0-9087

INCO

UTILIZATION OF METHANOL FUEL AS A TRANSPORTATION FUEL IN MINING OPERATIONS

(UP-I-103)

FINAL REPORT
BY
INCO LIMITED
2060 Flavelle Blvd.
Mississauga, Ontario

Work on this project was conducted under the auspices of the Canada Centre for Mineral and Energy Technology, Energy, Mines and Resources, Canada.

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MICROMEDIA

I. SUMMARY

Methanol substitution in a Deutz F8L-413 F/W diesel engine, used in underground mines, has been investigated in relation to conventional fuel savings and emission benefits to be gained.

Combustion of methanol/diesel fuel emulsions in the unmodified engine increases the peak cylinder pressures and rate of pressure rise, but these values do not exceed the manufacturer's recommended limits provided the methanol content of the fuel does not exceed 12% on an energy basis. The addition of 2.4% of a cetane enhancer to the fuel emulsion allows satisfactory engine combustion to be achieved with 15% methanol substitution on an energy basis over the full operating range of the engine.

An electronic controller, utilizing digital circuitry, was developed by Ontario Research Foundation to provide a fixed ratio methanol/diesel emulsion to the engine. This controller provided for emissions assessment of the effects of ignition improved 15% (E/E) methanol/diesel emulsion over a simulated transient load-haul-dump (LHD) mining cycle.

Steady state engine emissions test results show that total particulate and oxides of nitrogen (NO_x) emissions are reduced by about 20 to 25% with ignition improved methanol/diesel emulsion. Aldehyde emissions are reduced with methanol/diesel emulsion when the engine is operated over a computer simulated LHD cycle while maintaining reductions in particulate and NO_x emission.

The exhaust quality index (EQI) was used to assist in establishing the overall emissions effect of methanol/diesel emulsion. Results show that the EQI is reduced (improved) by about 17% with emulsion over the transient mines cycle. Improvements in exhaust quality are also observed at intermediate to high engine loads. There is, however, a deterioration in exhaust quality at light load conditions.

The need for using ignition improver in methanol/diesel emulsion increases the fuel cost considerably due to the high cost of the ignition improver.

Economics are presently unfavourable on a fuel substitution basis alone, but may improve if underground ventilation reductions benefits can be achieved, taking account of the need to control dust and blasting fumes and if reductions in the price of ignition improver are possible in the future.

II. INTRODUCTION

Diesel powered equipment is currently used extensively in underground mining operations in Canada, but there are increasingly stringent requirements for improved mine air quality. Ventilation of the mine is performed to remove diesel fumes, control dust and temperature levels, and remove blasting fumes. Occupational exposure to diesel exhaust emissions, particularly the soot content, has recently become more of a concern.

Previous work at Ontario Research Foundation (ORF) done under contract for Energy, Mines and Resources Canada has demonstrated that the soot emission from a truck diesel engine can be decreased by 40 to 50 percent by the partial substitution of methanol for diesel fuel in an emulsion*. Thus it was decided to try to use this technology to decrease the soot emission from the Deutz diesel engines used in underground mining equipment. An unsolicited proposal was submitted in July 1980 and a contract was awarded in February 1981. Because of its previous experience, Inco chose to award the experimental phase of the contract to ORF. Inco retain responsibility for project management and direction, acting through its process engineering department, in Mississauga, and its mining research department in Sudbury.

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* R.L. Cavanagh, C.K. Brown, "Impact of the Partial Substitution of Methanol in Industrial and Automotive Fuels", Progress Report No. 1, for Energy, Mines and Resources Canada, October 18, 1977.

III. OBJECTIVES

As stated in contract, the objectives are as follows:

1) To acquire or design, systems necessary to modify underground diesel engines for dual fuel operation on methanol and diesel oil.

2) To identify the emission characteristics arising from operating such engines on methanol/diesel fuels, and optimise emissions and performance.

3) to equip representative types of underground diesel powered vehicles with dual fuel systems, and carry out surface testing of the vehicles by mine operators.

4) To operate the modified underground vehicles in an experimental mine, and carry out a comparative study of mine air quality when the vehicles are fueled with a single diesel fuel and a dual fuel of methanol/diesel oil.

5) To equip a number of underground vehicles with dual fuel systems and operate the vehicles underground, on a production basis, at Inco Metals Company. Monitoring production from such duel fuel vehicles located in one level of the mine, with similar vehicles located in another level, operating on single diesel fuel, will allow identification of any deficiencies arising from the dual fueled vehicles.

IV. DESCRIPTION OF EQUIPMENT

All of the work performed by ORF has been reported in a separate document (Appendix III) prepared by the engineering sciences division of the centre for alternative fuel utilization, and dated September 28th, 1984. This report describes the following:

(1) properties of methanol
(2) test engine description
(3) emulsion fuel system development
(4) engine installation and test cell commissioning
(5) combustion and fuel injection studies instrumentation
(6) emissions testing equipment
(7) development of an LHD cycle
(8) Combustion studies test schedule
(9) emission studies test schedule
(10) test results
(11) engine inspection
(12) discussion
(13) conclusions.

The reader should refer to the ORF report for the detailed information as stated above.

(i) Choice of Mine Vehicle:

In the original proposal it was intended to investigate the use of methanol/diesel emulsion in either an underground dump truck, or a load-haul-dump (LHD) machine. It was decided to focus all of the work on the LHD machine since there are more of these in use in a typical modern underground mine using trackless mining equipment. Moreover, the LHD machine is used at full output of the engine for greater periods of time, and is generally running at full output when it is at the face of the mine. This is the point at which the machine loads the ore into the bucket and the engine is running at rated load. However, at the face of the mine the ventilation is generally the poorest since it is often at the end of a tunnel. Therefore, this application would yield the greatest overall benefits in terms of number of machines and air quality at the working face of the mine. For the purpose of the study, the duty cycle of an LHD machine was therefore used.

(ii) Choice of Engine

The major portion of the underground equipment at Inco is powered by Deutz type 714 air cooled diesel engines. These engines are however no longer currently in production, having been replaced by a similar Deutz series 413 engine. Many other mines in Canada also use the Deutz air cooled diesel engines. The Deutz series 413 engine is basically the same as the older series 714 engine and thus it was decided to purchase a new series 413 engine. This is the engine which is being installed on most of the new underground equipment at Inco, having recently purchased four LHD machines with the twelve cylinder version of this engine.

For the work at ORF, an eight cylinder version of the engine was purchased. The mining industry uses the version with indirect injection to improve the quality of the exhaust emissions. The engine is described in detail in the ORF report on pages 6 to 10, accompanied by photographs.

(iii) Choice of Technology

At the stage of proposal presentation, some discussion had been presented into the possibility of using a dual fuel injection approach to using methanol in the diesel engine, rather than using the emulsification technology. Upon further examination, it was concluded that the dual injection technology was too complex for the mining application, considering the small additional soot emission reductions possible when compared to the emulsification technolgy. Emulsification can be more readily retrofitted to an existing engine than the dual fuel injection system which requires two complete injection systems. In order to retrofit two injection systems, the engine would have to be completely rebuilt.

In addition, the degree of fuel substitution over the duty cycle of the scoop tram would not be as high as that over the truck duty cycle for which the dual fuel injection technology had been originally developed. In the case of the truck application, dual fuel injection permits up to 90% of the diesel fuel to be replaced with methanol. However, in an LHD machine, the extensive running at light load and idling would significantly reduce the amount of diesel fuel displaced, estimated to be more in the range of 50 to 60%. Emulsification technology was able to displace about 25% of the diesel fuel used in the truck cycle in the previous work at ORF. Both technologies were able to approximately halve the soot emissions from the engines.

Therefore it was decided to do all of the experimental work on the emulsification technology on the Deutz 413 engine using an LHD duty cycle for the dynamometer testing in the ORF test cell.

In the emulsion system, methanol is added to a fuel loop as shown in Figure 3 of the ORF report. The amount of methanol introduced to this loop is dependent on the fuel rack position, engine speed and the desired amount of diesel substitution. A Bosch mechanical hydraulic pump is used to supply 12000 kPa of emulsion pressure to the Hydroshear. The Hydroshear is an emulsifying device which mechanically emulsifies fluids with tangentially orientated shear zones. The resultant methanol/diesel emulsion is unstabilized and separates rapidly after approximately 45 seconds. This time period is, however, sufficient to allow for delivery of the emulsion to the combustion chamber prior to phase separation of the two fuels. During testing, emulsion quality is determined by taking a sample from the fuel loop and measuring the time for 80% separation of the two fuels.

Unstabilized methanol/diesel emulsions cannot be allowed to remain in the fuel system following engine shutdown since separation of the emulsion will occur. For this reason, all traces of methanol must be removed from the fuel system prior to stopping the engine. Also, due to methanol's lower energy density compared to diesel fuel, the maximum fuel rack travel must be increased when operating the engine with emulsion. Control of maximum fuel rack position relative to the percentage of methanol in the loop is complex, necessitating the development of a special purpose electronic control unit. The complexity arises from the rapid and varying demands of fuel quality and the relatively large volume of the recirculating loop.

These fuel system characteristics have resulted in the selection of a fixed methanol/diesel emulsion ratio throughout the engine operating range.

(iv) Acceptability of Methanol as an Underground Fuel

Properties of methanol are described in the ORF report on pages 4 and 5. To date, methanol has not been used in underground fuel applications and its use (and that of other volatile fuels) is specifically prohibited by the Ontario government. Discussions were held with the Ontario government and it was agreed that methanol could be used in an experimental demonstration for the present time. (see letters in Appendix I). The principal safety precaution suggested is the addition of approximately 7% pentane to the methanol. This will give the flame a distinct colour since pure methanol burns with no flame colour. In addition, the high vapour pressure of pentane will ensure that the mixture in the vapour space of the fuel tank will always be over rich and cannot therefore explode. This addition to methanol has been extensively demonstrated in Germany in fleet trials of methanol and is known there as M-100 methanol. For the purposes of the experimental work, however, 100% methanol was used in the emulsion, with some cetane improvers added for some of the tests.

(v) Development of Load Cycle for LHD Machine

A literature survey was made of published LHD cycles and none was felt to be completely representative. The data base is complicated by the presence of a large load to operate the hydraulic systems on the LHD. This load varies from one type of machine to another and also varies with the operating practice of the mine and the mine layout.

Therefore it was decided to acquire experimental data using an LHD typical of that used in Inco mines. At the time, Inco did not have a Deutz 413 engine on a five yard LHD, but Falconbridge did have a suitable machine in their Lockerby mine and they were willing to cooperate with Inco and ORF. This work is reported in more detail in the ORF report, pages 36 to 39. Following the development of the cycle, it was discovered that the fuel injection pump rating specifications would not be suitable for Inco mining operations. Rated speed condition for the Deutz engines is 2300 RPM at the Inco mines whereas the Falconbridge mine set the rated speed to 2000 RPM. It has been suggested that this reduction in rated speed will decrease the maximum tramming speed of the mine vehicle.

It was decided, therefore, to utilize the MTU-LHD cycle (developed by John Johnson and Associates of Michigan Technological University) for the emissions test work under this contract. This cycle was derived from a Wagner ST-5 vehicle operating in a copper mine. A Deutz F8L 714 engine was used for the cycle development, and rated speed was set at 2300 RPM.

The MTU-LHD cycle is divided into four modes as follows:

Mode 1 - Driving into the drift from a cross-cut.

Mode 2 - Loading at the face (mucking).

Mode 3 - Hauling out of the drift from face of cross-cut.

Mode 4 - Hauling from cross-cut to dump point, dumping, and tramming to cross-cut from dump point.

The load cycle was then programmed onto the computer controlled dynamometer at ORF for the load cycle and emission testing.

(vi) Methanol/Diesel Emulsions Test Equipment:

Installation of the test engine in the ORF test cell is described in detail in their report on pages 11 to 35. The engine was originally run on diesel fuel to confirm engine performance and obtain typical emissions data using diesel fuel. Problems with the engine soon developed and extensive consulting had to be done with the manufacturer to resolve the problem of cylinder wall glazing and valve problems. This necessitated disassembly of the engine and replacement of some parts under warranty. However time was lost in the overall project schedule because of this.

The apparatus used by ORF to collect the exhaust emissions for analysis is described in their report in detail. Emissions were measured for various load speeds as well as over the LHD cycle. Measurements consisted of particulates, carbon monoxide, totyal hydrocarbons, nitrous oxides, all oxides of nitrogen, aldehydes and unburnt methanol.

(vii) On-Board System Development

The components were developed to be as rugged as possible for possible future use in an on-board mode on an LHD machine. However, no work was done on an actual LHD machine since the experimental results were not sufficiently promising to merit such an expenditure of money. Therefore, the underground evaluation was also not carried out. By agreement with the Scientific Authority, some preliminary work was done into an investigation into the use of 100 % methanol in a mine engine as this seems to hold better promise for improving emissions, particularly the soot emissions which are the most bothersome. This later work was submitted in the form of a trip report in August 1984.

(viii) Equipment Acquired

During the course of the contract, Inco did not acquired directly any capital equipment. However, ORF did purchase the following capital equipment and charged the costs to the contract:

	Item	Manufacturer	Purchase Value
1.	Engine S/N 6283999	Deutz	$ 22,991.37
2.	Wave Form Analyzer	Norland	$ 28,671.64
3.	Fuel Pressure Transducer	AVL	$ 1,032.32
4.	Water Valve	Canadian Worcester Controls	$ 1,320.49
5.	Hydraulic Pump	Bosch	$ 1,143.62

The equipment is currently installed in one of the engine test cells at ORF and is in good operating order. It is recommended that approximately $5000 be left in the contract budget for removal of the equipment and restoration of the test cell for possible future use. The explosives atmospheres laboratory of CANMET has indicated an interest in acquiring the Deutz diesel engine at the end of the contract. This sum should be sufficient to remove the engine, prepare it for shipping and ship it to Ottawa. Unless so directed otherwise, the balance of the equipment which is now three years old will be left at ORF.

V. DISCUSSION OF EXPERIMENTAL RESULTS:

The experimental results are presented in detail in chapter 12 of the ORF report, and the reader is referred to this document for details. The first experiments were performed to measure the pressures in the cylinders and the rate of pressure rise. These measurements were made to make certain that the design specifications for the engine were not being exceeded, and the amount of methanol and injection timing were adjusted accordingly. Methanol was used both with and without cetane improver for the combustion studies.

Emissions measurements were then made over a series of steady state load speeds, and then over a transient LHD cycle, for both ignition improved emulsion and standard diesel engine operation. Fuel efficiency of the engine was also measured and compared.

(i) Combustion Characteristics with Methanol/Diesel Emulsions:

In the first series of tests, methanol without cetane improver was emulsified with number one diesel fuel. It was found that an emulsion containing 12 % methanol (blended on an energy percentage basis) could be used in the engine without exceeding the limits of cyclinder pressure and rate of pressure rise recommended by the engine manufacturer. However, brake specific fuel consumption on an energy basis (BSEC) is increased considerably. The increase in fuel energy which had to be supplied to the engine ranged from 4 to 20 percent depending on the load speed range. This is a disappointing result since other work at ORF with the Deutz 714 engine had indicated about the same BSEC on emulsions as on straight diesel fuel. It was possible to get better BSEC by advancing the timing of the injection, but the manufacturer's suggested rate of change of pressure rise was exceeded at the low end of the torque range of the engine. Therefore, it was concluded that attempts should be made to improve the operation of the engine on emulsions by adding a cetane improver to the methanol phase.

The cetane improver chosen for the work was octyl nitrate which was added to the methanol in ratios ranging from 1.5% to 3% on a volume basis in the emulsion. Based on the measurements of the rate of change of pressure rise, peak cylinder pressures and BSEC, it was concluded that the best ratio for the cetane improver was 2.4%. This resulted in a BSEC with a 15% methanol/diesel emulsion (percentage on energy basis) comparable to that obtained with a straight diesel fuel. This was the fuel used for the emission test work.

(ii) Emission Characteristics

The emission results are presented in summary form in figures 21 to 26 in the ORF report. For the sake of brevity, the results are summed up in bar chart form in figure 1 overleaf. It can be seen that the particulates are decreased by 25 % in total, together with a 20 % decrease in nitrogen oxides, despite the use a nitrate cetane improver. Carbon monoxide is increased slightly, but surprisingly, the aldehydes are decrased by over 30%

A formula has been proposed which addresses the overall impact of diesel exhaust pollutants, simultaneously present, on the mine air quality*. The formula, developed by I.W. French and Associates, takes into account specific threshold limit values (TLV's) for gaseous pollutants and respirable combustible dust (RCD). Although this formula, designated the air quality index, is primarily intended for mine air quality assessments, it has been used to evaluate the effectiveness of diesel emission control strategies. Thus, an exhaust quality index (EQI) has been derived. The exhaust quality index is expressed as follows:

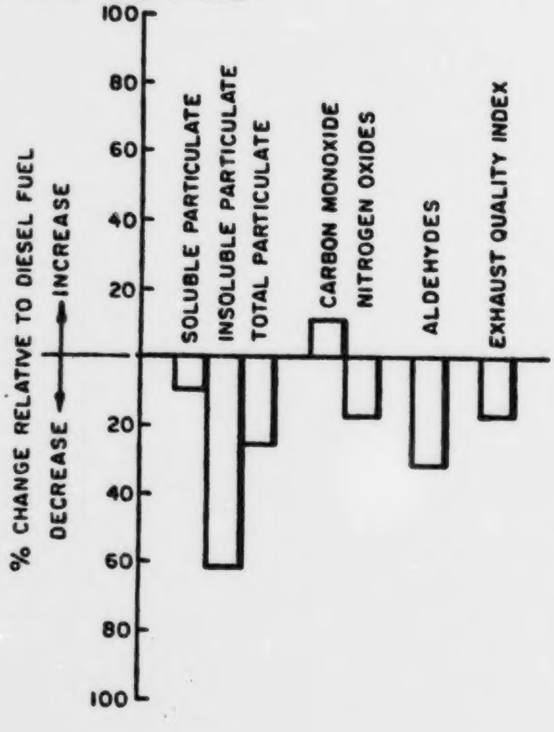
$$EQI = \frac{CO}{TLV_{CO}} + \frac{NO}{TLV_{NO}} + \frac{RCD}{TLV_{RCD}} + 1.5\left[\frac{SO_2}{TLV_{SO_2}} + \frac{RCD}{TLV_{RCD}}\right] + 1.2\left[\frac{NO_2}{TLV_{NO}} + \frac{RCD}{TLV_{RCD}}\right]$$

---

* J.P. Mogan and E.D. Dainty, "Emission Control Performance of Diesel Exhaust Treatment Devices", Industrial Hygiene for Mining and tunneling, Proceedings of a Topical Symposium, Denver, Colorado, pp 154-161, November 6 and 7, 1978.

FIGURE 1

EFFECTS OF IGNITION IMPROVED 15% (E/E) METHANOL/DIESEL EMULSION ON EMISSIONS OVER THE MTU-LHD CYCLE.



This formula reflects the concern of the synergistic effects of RCD, or diesel exhaust particulate, with SO_2 and NO_2 as indicated by the respective weighting factors of 1.5 and 1.2.

The EQI was caluclated for the engine using straight diesel fuel and the engine using emulsion. The EQI dropped from 168 to 135 which is sufficient that a small reduction in ventilation may be possible.

(iii) Economic Assessment

In order to assess the benefits of reduced emissions, a useful tool exists in the form of the exhaust quality index (EQI) as described above. This index, derived from medical considerations, attempts to quantify the risk of exposure to various levels of mine air contamination with exhaust pollutants. Further, Dainty and Mogan(*) have quantified the decreased costs due to ventilation reduction through emission control hardware. It is therefore possible to apply the emissions data from the present program to determine the impact on the EQI, and compare the benefits of decreased ventilation costs with the cost impact of methanol utilization.

Table 1 shows the results of this assessment. Operating costs only are considered. Calculations are based on diesel fuel costs of $0.273/L (mining fuel is tax exempt), methanol cost of $0.15/L, and cetane improver cost of $3.89/L. Fuel consumption is based on 170,000 kJ per hour per machine per year and a utilization rate of 2880 hours per year. Total ventilation costs are estimated at $7,000,000 per year with a working threshold of 25% of this cost for diesel emissions control. Therefore, a reduction of 50% in the EQI would result in an estimate savings of $875,000 in ventilation costs for the mine in one year.

* E.D. Dainty, J.P. Mogan, "Analysis of the Economic Impact of Diesel Exhaust Emissions Toxicity Reduction Strategies; Part I Filtration", MRP-MRL, Report No. 81-132 (TR).

The 12% emulsion results in an increase of 12% in fuel costs over the currently used IDI diesel engines, largely due to the increased BSEC. Emissions data are not available for the 12% emulsions and the EQI could not be calculated. It is estimated however that as a result of the unsatisfactory combustion, the EQI would be close to that of the conventional diesel engine. With 15% emulsion, fuel costs are increased by 29%, primarily due to the cost of the cetane improver ($3.89/L), over the base condition. With an EQI of 135, an annual savings in ventilation costs of $875 per machine per year is estimated and results in a net cost increase of $201 per machine per year.

The use of methanol/diesel emissions in unmodified Deutz 413 series underground diesel engines will therefore only prove to be economic if lower cost cetane improvers can be found, and a greater differential develops between methanol and diesel fuel costs.

TABLE 1

ESTIMATED NET OPERATING BENEFITS OF METHANOL UTILIZATION IN UNDERGROUND MINES

Fuel	Fuel Costs $/Machine/Year	Annual Incremental Fuel Cost Over Diesel $/Machine/Year	EQI	Annual Savings In Ventilation Costs $/Machine/Year	Net Benefits $/Machine/Year
Diesel	3,750	-	168	-	-
12% Methanol/Diesel Emulsion	4,214	464	-	-	-
15% Methanol/Diesel Emulsion with Cetane Improver	4,826	1,076	135	875	-201

CONCLUSIONS:

1. Substitution of methanol for diesel fuel in the form of an unstabilized emulsion in a Deutz 413 diesel engine results in unsatisfactory combustion characteristics with significant increases in brake specific energy consumption.

2. To achieve brake specific energy consumption comparable to that of a 413 engine using straight diesel fuel, about 2.4% ignition improver (volume basis) must be added to the emulsion which contains 15% methanol on an energy basis.

3. Emissions over the LHD machine load cycle decrease about 20% when measured as the exhaust quality index, for an engine using the methanol/diesel emulsion with ignition improver added to the methanol phase.

4. Although the decrease in emissions may permit a modest reduction in mine ventilation costs, the decrease in ventilation cost is not offset by a decrease in fuel cost for the machine, since methanol costs more than diesel fuel on an energy basis and the small amount of ignition improver adds significantly to the total fuel cost.

Appendix I

Correspondence Regarding Acceptability of Methanol as a Fuel for use Underground.

Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

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Recherche et Technologie

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Your file Votre référence

Our file Notre référence

Pr. No. 4.3.0.2.02.01

October 5, 1984.

Mr. P. B. McCrodan,
Director,
Mining Health & Safety Branch,
Ministry of Labour,
400 University Avenue,
Toronto, Ontario
M7A 1T7

Dear Mr. McCrodan:

Thank you for your reply to my letter of June 22 granting permission for the underground trials of the 100% methanol engine. The contractor, Inco Ltd., proposes to use a glow-plug equipped Deutz 413 series engine developed by KHD Germany for this investigation. Since this class of engine would fit directly into the majority of underground machines, it would thus appear that this concept would provide the least disruptive route by which existing dieselized mines could cope with a significant shortfall in premium diesel fuel.

Should this shortfall occur, I would hope that the technology developed (explosion-proof fuel tanks equipped with flame traps, dual hose filling systems or vapour traps etc.) would permit a re-consideration of the prohibition of this water-extinguishable flammable fuel under Section 28(4).

Sincerely,

Paul Mogan,
Research Scientist
Canadian Explosive Atmospheres
Laboratory.

PM/dm
c.c. 1. T. C. Burnett
2. D. Gladwin
3. E. W. Mitchell

Canada

8J8738

OCTOBER 30 1980

TELEX NO 0533586

MR P MOGAN
MINING RESEARCH LAB
CANADIAN EXPLOSIVE ATMOSPHERE LAB
CANMET
DEPT OF ENERGY MINES AND RESOURCES

BT
OUR FILE MHS -06.52
RE PROPOSAL UP-I-103 PROPOSED BY INCO METALS COMPANY FOR THE UTILIZATION OF METHANOL FUEL AS A TRANSPORTATION FUEL IN MINING OPERATIONS
OUR FILE MHS-062.52 METHANOL

THE MINING HEALTH AND SAFETY BRANCH OF THE ONTARIO MINISTRY OF LABOUR IS RECEPTIVE TO THE RESEARCH OF METHANOL AS A SUBSTITUTE OR ADDITIVE FOR DIESEL FUEL IN UNDERGROUND OPERATIONS AFTER THE INITIAL STAGES OF THIS RESEARCH: WHICH INCLUDES PHYSICAL PROPERTIES OF METHANOL FLASH POINT EXPLOSION LIMITES ASSESSMENT OF HAZARDS HAVE BEEN COMPLETED THEN THIS BRANCH WILL RE-ASSESS FROM ALL HEALTH AND SAVETY ASPECTS FUTURE APPROVAL OF THIS CONTINUED RESEARCH

IF AND WHEN RESEARCH ON METHANOL FUEL IS CONTINUED UNDERGROUND THEN THIS BRANCH MUST HAVE ASSURANCES THAT COMPETENT SENIOR SUPERVISORY PERSONNEL ARE IN ATTENDANCE AT ALL TIMES DURING THE TRANSPORT OR TESTING OF THIS FUEL

PB MCCRODAN P ENG
DIRECTOR
MINING HEALTH AND SAFETY BRANCH
MINISTRY OF LABOUR

CC TO DR A ROBINSON
CHIEF ENGINEERS

M R BELCOR OTT

APPENDIX II

NULL

DISCLOSURE CERTIFICATION

Contract File Number:	23SQ.23440-0-9087
Contract Serial Number:	1SQ80-00172

We certify that there are no disclosures to submit under the above referenced contract, referred to in Section 4 of DSS 1036.

Signature: ....
Name

Mgr. Process Sales
....
Official Title

ONTARIO**RESEARCH**
FOUNDATION

ENGINEERING SCIENCES DIVISION
Centre for Alternative Fuel Utilization

UTILIZATION OF METHANOL AS A TRANSPORTATION FUEL IN MINING OPERATIONS

Final Report No. 3670

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Attention: Dr. T.C. Burnett

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September 28, 1984

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UTILIZATION OF METHANOL AS A TRANSPORTATION FUEL IN MINING OPERATIONS

1. SUMMARY

This report summarizes the activities and results of a program to operate a mines diesel engine on unstabilized methanol/diesel emulsion. Combustion pressures and emissions were measured to determine the maximum level of diesel fuel displacement using methanol as an alternative fuel. A Deutz F8L-413 F/W, indirect injection, air-cooled diesel engine was used for test purposes.

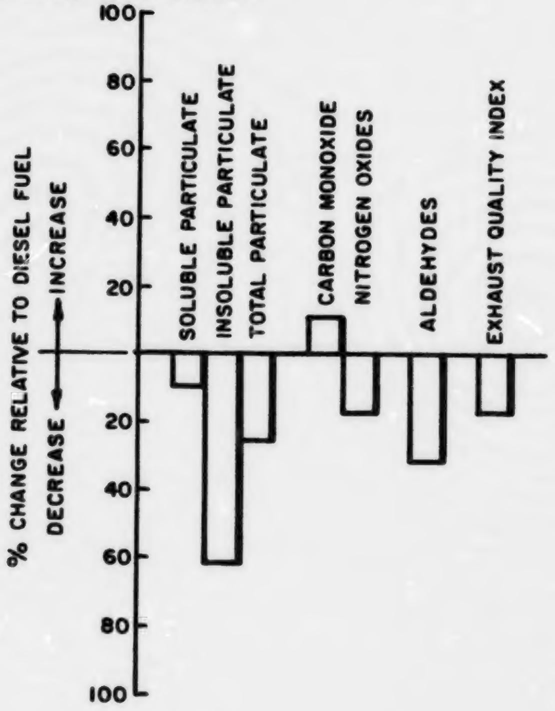
Combustion pressures and maximum rates of combustion pressure rise are generally increased when 12% (E/E) methanol/diesel emulsion is used as a fuel. Ignition delay is also evident due to the very low ignition quality and high latent heat of vapourization of methanol. Attempts to reduce ignition delay by advancing the static fuel injection timing generally result in higher peak combustion pressures and rates of pressure rise. Engine efficiency is reduced substantially with application of 12% (E/E) methanol/diesel emulsion.

It was determined that ignition improver must be added to the emulsion to improve the combustion and emissions quality of the engine. A concentration of 2.4% (V/V) octyl nitrate ignition improver in 15% (E/E) methanol/diesel emulsion was selected on the basis of acceptable emissions, combustion, engine efficiency and fuel cost.

An electronic controller, utilizing digital circuitry, was developed by ORF to provide a fixed ratio methanol/diesel emulsion to the engine. This controller provided for emissions assessment of the effects of ignition improved 15% (E/E) methanol/diesel emulsion over a simulated transient load-haul-dump (LHD) mining cycle.

Steady state engine emissions test results show that insoluble particulate and oxides of nitrogen (NO_x) emissions are reduced considerably with ignition improved methanol diesel emulsion. These reductions are at the expense of increased aldehyde emissions. Aldehyde emissions are reduced with methanol/diesel emulsion, however, when the engine is operated over a computer simulated LHD cycle while maintaining reductions in particulate and NO_x emission.

SUMMARY
EFFECTS OF IGNITION IMPROVED 15% (E/E)
METHANOL/DIESEL EMULSION ON EMISSIONS OVER
THE MTU-LHD CYCLE.



The exhaust quality index (EQI) was used to assist in establishing the overall emissions effect of methanol/diesel emulsion. Results show that the EQI is reduced (improved) by about 17% with emulsion over the transient mines cycle. Improvements in exhaust quality are also observed at intermediate to high engine loads. There is, however, a deterioration in exhaust quality at light load conditions.

The need for using ignition improver in methanol/diesel emulsion increases the fuel cost considerably due to the high cost of the ignition improver combined with the low cost of diesel fuel (diesel fuel used in mining operations is tax exempt) and is considerably cheaper than methanol on an energy basis. This increased cost may be partially offset by reductions in ventilation requirements for underground mines for those mines for which a reduction in ventilation is possible.

2. INTRODUCTION

Diesel engines are used extensively to power machines in underground mining operations. Diesel powered machines have the advantage of mobility over their electric powered counterparts. The disadvantage of using the diesel engine in the underground mine is the need to increase the ventilation of the mine environment to reduce worker exposure to diesel exhaust emissions. Ventilation is also required to control the dust level in the mine and reduce the temperature in deep mines. Mine ventilation is expensive both in equipment capital cost and operating and maintenance costs. Currently, regulations require 21 m^3/min of ventilation air for each kW of engine output. Proposed reductions in pollutant exposure limits would further aggravate the cost. In addition, it is expected that diesel fuel quality will deteriorate and result in poor exhaust emission quality.

The security of diesel fuel supply in the long term is uncertain. Concerns have been raised by the Canadian Government regarding the balance of gasoline and diesel fuel in Canada. Reductions in the use of gasoline which are currently underway would upset this balance and possibly create a shortage of supply of diesel fuel. There is, therefore, increasing pressure in the industrial and government sectors to find methods for utilizing alternative fuels for partial and/or complete substitution of diesel fuel in compression ignition engines. Methanol is currently the most promising alternative fuel for this purpose.

A contract was let by the Canada Centre for Mineral and Energy Technology (CANMET) to INCO Limited for the evaluation of unstabilized methanol/diesel emulsion as a fuel for a typical mine machine. Ontario Research Foundation (ORF) was issued a subcontract by INCO to perform the test work for the contract. The program was defined to determine the maximum displacement of diesel fuel using methanol in a Deutz F8L-413 F/W diesel engine and examine the emissions characteristics.

This report summarizes the activities and results of the test program in terms of combustion studies, fuel consumptions and emissions. Development of an electronic controller for regulating the feed of methanol to the fuel system is described. The exhaust quality index (EQI) is used to compare the overall emissions impact of using unstabilized methanol/diesel emulsion.

3. PROPERTIES OF METHANOL

Methanol is a clear, colourless and virtually odor-free liquid at normal conditions. The chemical formula for methanol is CH_3OH and may be considered as two molecules of hydrogen (H_2) chemically liquefied by one molecule of carbon monoxide (CO). The oxygen constitutes 50% of the molecular weight and forms the hydroxyl group in the molecule resulting in a liquid that is strongly polar in nature. Most other hydrocarbon fuels are non-polar.

The stoichiometric equation for the combustion of methanol in oxygen is as follows:

$$CH_3OH + 1.5O_2 \longrightarrow CO_2 + 2H_2O$$

Combustion of one mole of methanol in air requires 7.295 moles of air. Methanol has an energy density of 22,661 kJ/kg based on combustion to liquid water (25°C). This energy density is approximately half that for typical diesel fuel and gasoline. Assuming equal work per unit mass of the fuel, it would be necessary for the fuel tank volume for methanol to be double that for conventional fuel to achieve the same energy content.

Methanol has a very high specific heat of vapourization (1.167 kJ/kg at 25°C). This characteristic is a disadvantage to its use as a fuel in compression ignition (CI) engines. Vapourization following injection of methanol in the combustion chamber of a CI engine lowers the temperature of the cylinder air change and thereby effects combustion.

The high polar nature of methanol causes a relatively low vapour pressure and high boiling point compared to molecules of similar molecular weight. Evaporation of methanol in a tank at room temperature creates a potentially explosive mixture (in air) when the methanol vapour content reaches 6% (v/v), the lower explosive limit (LEL). Mixtures of methanol in air above 36% (v/v) are non-ignitable since the mixture is too rich to burn. The equilibrium methanol/air mixture at 20°C is 12.6% (v/v) and is, therefore, explosive. These characteristics require special handling and storage methods compared to that used for diesel fuel.

Methanol contains no carbon to carbon bonds and, therefore, cannot form any unoxidized carbon particles or precursors to soot particles. Pure methanol produces no soot and has a bluish flame with low luminosity that is nearly invisible in daylight. Recognizing and fighting fires might present a problem. Higher hydrocarbons, such as toluene, have been added (2% v/v) to methanol to improve the flame luminosity.

The physical and chemical properties of methanol are summarized in Table 1.

4. TEST ENGINE DESCRIPTION

The diesel engine (Serial Number 6283999) used for the test program was a Deutz F8L-413 F/W with a rated output of 136 kW (185 BHP) at 2300 RPM. This air-cooled engine is used by the mining industry to to power equipment such as load-haul-dump (LHD) vehicles as shown in Figure 1. The engine is naturally aspirated employing two-stage combustion (indirect injection) which results in reduced emissions compared to a turbocharged direct injection engine. Individual cylinder units are used on this engine to facilitate air cooling. Bore and stroke of this engine series are 125 mm (4.92 inches) and 130 mm (5.12 inches) respectively, resulting in a total displacement of 12.8L (781 cubic inches) for the eight cylinder version. Cylinder banks are in a 'Vee' configuration. Oil sprays are directed at the bottom (underside) of each piston for cooling purposes. Figure 2 shows the engine installed in the test cell.

The Deutz F8L-413 F/W diesel engine incorporates a Robert Bosch in-line fuel injection pump (Model PE8A 95D410LS 2588). A flexible coupling is used to drive the injection pump at one-half crankshaft speed via a gear set at the flywheel end of the engine. The fuel injection timing is automatically advanced with increasing engine speed by a mechanical centrifugal advance device. This device is connected via the final drive gear to the injection pump. Standard injection timing (static) for this engine is 14 degrees before top dead centre (^{o}BTDC). The mechanical advance unit automatically increases the injection timing with increasing engine speed as follows:

Engine Speed	RPM	1200	1400	1600	1800	2000	2200	2300	2460
Injection Timing	^{o}BTDC	14	14	16	17	18	19	19.5	20

FIGURE 1
Typical Installation of a
Deutz F8L 413 F/W Diesel Engine
in a Jarvis Clark ST500
LHD Machine

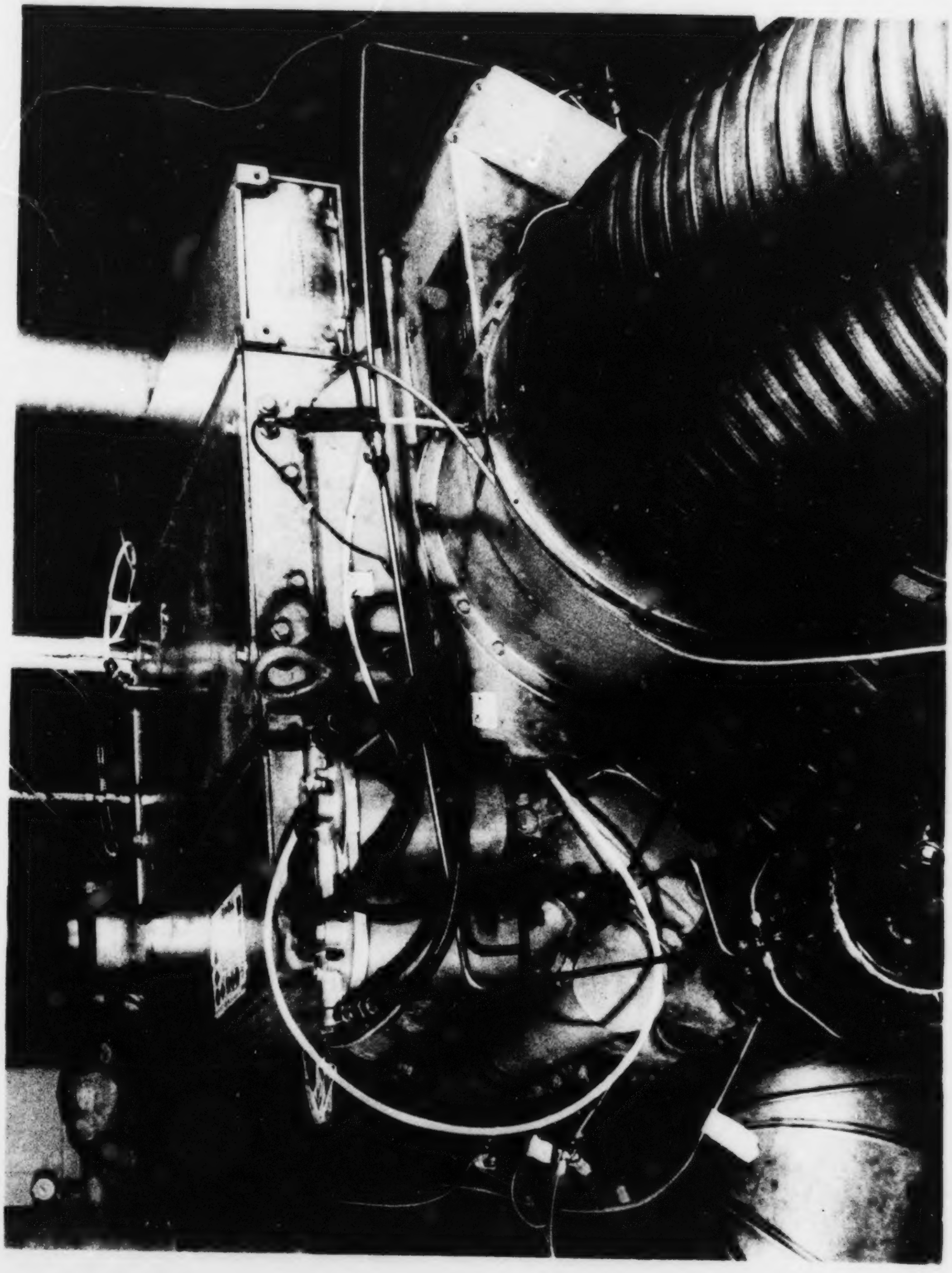


FIGURE 2 Deutz F8L-413 F/W installed in test cell.

In a normal vehicle installation the fuel is pumped from a fuel tank with the lift pump (located on the injection pump) and delivered to the injection pump via two fuel filters. Filtered fuel enters the fuel chamber at approximately 172 kPa (25 psig) and supplies each of the pumping elements with sufficient fuel. The plunger, connected to a control rod, meters the required amount of fuel for delivery to the combustion chamber (see Figure 2). As the plunger moves up the barrel it pressurizes the fuel and lifts the delivery valve off its seat. The pressurized fuel is transferred to the appropriate injector. Pressurized fuel then raises the injector needle valve thereby providing a route for the fuel to enter the swirl chamber through the nozzle hole. A small amount of fuel passes between the injector trunk and body for lubrication purposes. This excess fuel is returned to the fuel tank.

The governor is used to control the amounts of fuel delivered to the combustion chamber based on demand (i.e. required engine speed and load). A Bosch model RQV governor is normally used on the Deutz F8L-413 F/W engine. In some applications the RQV governor is removed and replaced with an RSV governor. Some feel that this alteration improves engine response to changes in load, particularly on torque converter equipped engines. Klochkner-Humboldt-Deutz (KHD) AG do not approve of using the RSV governor on the 413 F/W series engine when used in mining applications.

High idle is normally set to 2460 - 2480 RPM. These settings provide a speed droop of 7.4%. Peak torque occurs at approximately 1500 RPM resulting in a torque rise of about 14%. Engine idle is set to approximately 600 RPM.

Industry complaints of excessive oil discharge via the engine exhaust prompted several modifications by KHD. As a result of these required modifications, the test engine was returned to Deutz Canada in Mississauga prior to starting the test program. All cylinder liners were deglazed and modified piston rings installed. New valves and valve stem oil seals were installed. The old valves were stamped with an identification number in the area where the valve stem travels past the oil seal. Irregularities in the stem, caused by the stamping, deteriorated the stem oil sealing. A modified set of blower reduction gears was installed to reduce blower speed. The original gear set provided excessive cylinder cooling under high engine speed and low load conditions.

After approximately 70 hours of engine operation during initial stages of the test program, crankcase oil began dripping out of the exhaust manifolds. KHD attributed the problem to extended engine operation under light or no-load conditions causing the cylinder liners to become glazed. Glazed cylinders lead to crankcase oil pumping past the rings and liner. KHD stated that the 413 series must not be operated for more than one half hour at no load or glazed liners will result. There was no documentation to support KHD's recommendation and ORF staff were not made aware of this problem.

The engine cylinder units were dismantled, cylinder liners deglazed and new piston rings installed. New valves (both intake and exhaust) along with new valve stem seals were installed again. These new piston rings and valves were claimed to be of an improved design over the original replacement parts. Following repairs the engine was operated over a predefined load/speed schedule in accordance with that specified by KHD. This schedule was conducted to ensure satisfactory seating of piston rings and valves.

Although the engine was operated under load for the duration of the 300 engine hour test program, high oil consumption again became evident at approximately 200 engine hours. Subsequently, the engine was operated under high load and speed conditions in an effort to alleviate the oil discharge problem with reasonable success. Dismantling of one cylinder unit on completion of the test program revealed that the cylinder cross-hatch was still present. It is uncertain as to why the oil charge problem occurred at 200 engine hours. It was beyond the scope of the present study to ascertain the source of this problem.

5. EMULSION FUEL SYSTEM DEVELOPMENT

5.1 General

The application of unstabilized methanol/diesel emulsions to a compression ignition engine requires physical changes to the original fuel injection system. Unstabilized emulsions of methanol/diesel separate rapidly (approximately 45 sec) following the emulsification process. This phase separation is undesirable since the fluidic properties of the two fuels can effect metering of the fuel charge and ensuing combustion. Also, methanol that has separated from the diesel fuel can chemically attack components of the fuel system. It is essential, therefore, that the excess fuel from the injection pump be returned to the emulsification device to minimize phase separation.

A HydroShear, developed at ORF, was used for the emulsification of the methanol and diesel fuels. This device employs liquid, or hydrodynamic shear forces, that have been imparted by the tangential acceleration of the two liquids. The HydroShear(R) has no moving parts and is installed directly in the fuel system loop. Energy to the HydroShear is provided by a pump which creates a pressure drop across the device of about 150 to 200 psi (1000 to 1400 kPa). Under these conditions it is estimated that an emulsion is formed with a particle size of a few microns.

Initial development of the emulsion fuel system was intended for steady-state operation to study the effects of the emulsion on combustion characteristics. During the course of this development, consideration was given to using components that would be suitable for on-board vehicle use in an underground mining environment.

The following subsection describes the components of the emulsion fuel system and its modus operandi. Figure 3 illustrates a schematic of the emulsion fuel system.

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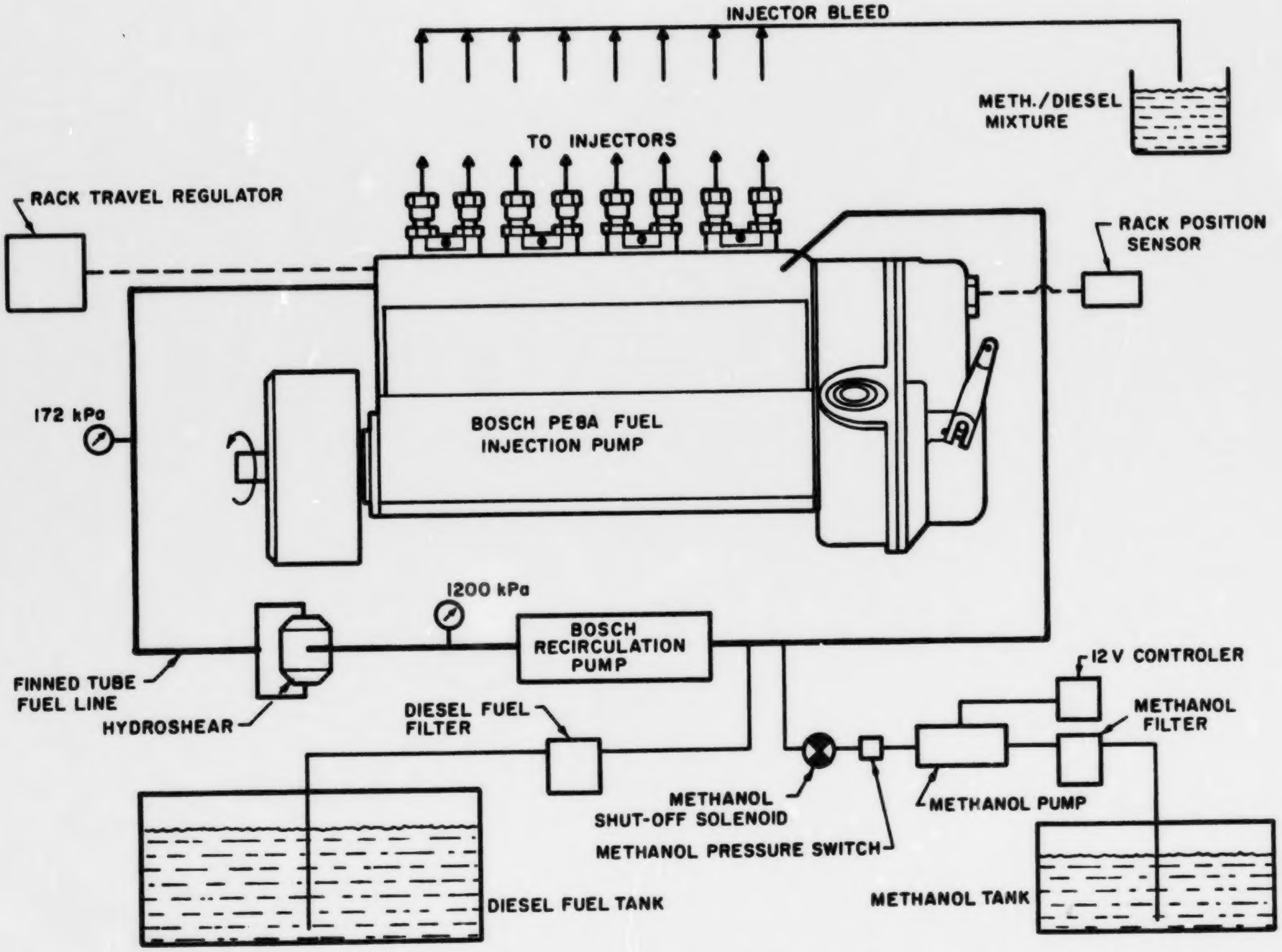
INJECTOR BLEED
METH./DIESEL MIXTURE
TO INJECTORS
RACK TRAVEL REGULATOR
RACK POSITION SENSOR
172 kPa
BOSCH PE8A FUEL INJECTION PUMP
1200 kPa
BOSCH RECIRCULATION PUMP
12 V CONTROLER
FINNED TUBE FUEL LINE
HYDROSHEAR
DIESEL FUEL FILTER
METHANOL FILTER
METHANOL SHUT-OFF SOLENOID
METHANOL PUMP
METHANOL PRESSURE SWITCH
DIESEL FUEL TANK
METHANOL TANK

Figure 3: DIESEL/METHANOL EMULSION SYSTEM FOR A BOSCH PE8A INJECTION PUMP.

5.2 System Construction

A gear type, high pressure hydraulic pump was used to supply fuel pressure to the HydroShear. A Bosch Model HY/ZFS11/4 L203 was selected for this purpose since it provided direct installation on the engine with mechanical drive obtained from an engine gear set. Electrically operated pumps were considered; however, they would require explosion proofing due to the presence of methanol. Additional mounting hardware and the need for an upgraded vehicle charging system were factors that negated the use of electric pumps. Figure 4 shows the installation location of the Bosch gear pump on the engine.

The engine manufacturer provided sets of drive adapters and mounting hardware for the Bosch pump. A pressure relief valve on the pump discharge port allowed for the adjustment of discharge pressure to suit the pressure requirements for the HydroShear.

Due to the long lead time to acquire the correct pump from Germany, the Canadian distributor supplied a similar pump to suit our application. The distributor reversed the direction of rotation of the in-stock pump unit. This pump failed after only a few hours of service. Damage was limited to sheared teeth in the pump and a twisted drive shaft. It was determined that the Canadian supplier had incorrectly changed the direction of rotation of the pump. An electrically operated pump was substituted for interim testing while the supplier honoured the warranty and provided a new Bosch pump. Delivery of this new pump from Germany required two months. The new Bosch pump performed flawlessly for the duration of the test program.

The temperature of the injection pump return fuel is higher than the supply fuel due to conductive heat transfer in the injection pump. Also, there is a fuel temperature rise across the Bosch hydraulic pump. It is necessary therefore, to reduce the return fuel temperature prior to re-introduction to the injection pump. A liquid/liquid, tube and shell type heat exchanger was used for this purpose. City water was used on the shell side of the heat

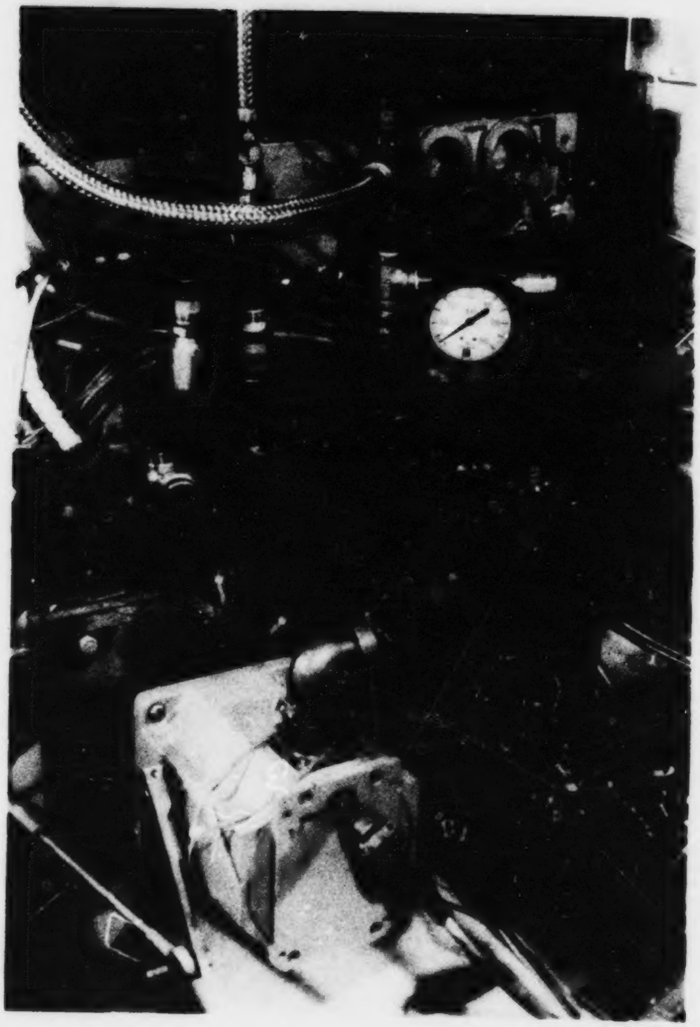

FIGURE 4

Installation of
Bosch Gear Pump
on Test Engine

exchanger with the emulsion fuel on the tube side. Finned tube fuel lines were considered for use on the test vehicle to take advantage of the air flow used for cooling the engine.

Methanol was supplied to the recirculating fuel loop with a Tuthill gear pump (Model 9235). This pump is electrically operated with a voltage supply up to 12 VDC. Methanol flow rate to the fuel system was adjusted with a variable voltage DC power supply. Pump components are comprised of a stainless steel head, nickel alloy gears, stainless steel shafts and a magnetic motor coupling. Methanol flow rate was measured continuously using a Fluidyne Model 213 flowmeter. Filtration of the methanol was accomplished with a methanol compatible filter supplied by Volkswagen AG.

The HydroShear uses small diameter nozzles to create the pressure necessary for emulsification of the two fuels. Selection of the nozzle diameter was based on a trade-off between sufficient pressure drop across the HydroShear to obtain a fine emulsion while maintaining the same fuel flow characteristics as the original Deutz fuel system. Nozzles with a 1.40 mm inside diameter were selected after several pressure versus flow tests. These nozzles provided satisfactory fuel flow characteristics over the entire engine operating range while maintaining a HydroShear pressure drop of approximately 200 psi.(1400 kPa).

5.3 Development of an Electronic Methanol/Diesel Fuel System Controller

Fuelling of a diesel engine with unstabilized methanol/diesel emulsion requires that the amount of methanol fed to the fuel system be controlled according to engine conditions. The large fuel volume of the injection system loop prevented the adjustment of the methanol to diesel ratio according to engine conditions. It was necessary, therefore, to operate the engine on a fixed ratio of methanol/diesel emulsion. Following a review of the fuel management system it was decided that an electronic controller be developed for the metering of methanol to the fuel emulsion loop. This approach allowed for subsequent adjustment of the methanol to diesel ratio if necessary.

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The controller, illustrated in Figure 5, uses electronics and control logic. Engine speed and fuel rack position are used as the input variables to determine the fuelling rate of the engine. A programmable read only memory (PROM) reads the input variables and adjusts the DC voltage to the methanol pump to regulate the flow of methanol where methanol pump motor voltage is proportional to methanol flow. A methanol pressure switch is used by the controller to signal a low pressure condition. The controller also incorporates an input to signal when engine temperature conditions are met via a temperature switch. Conditions of proper methanol pressure and engine temperature must be met in order to enable the controller output.

Fuelling the engine with methanol/diesel emulsion requires extending the maximum fuel rack travel in the injection pump to compensate for the lower energy content of methanol. This adjustment can seriously overfuel the engine when operating on standard diesel fuel. For this reason, a fuel rack compensation logic was incorporated into the controller. This provision allows for the methanol concentration in the emulsion to increase to a nominal percentage prior to increasing the maximum rack travel. The disadvantage of this is that the engine will be underfueled for the period when methanol is introduced to when the rack travel is extended.

A complete description of the development of the methanol controller is given in Appendix B

6. ENGINE INSTALLATION AND TEST CELL COMMISSIONING

6.1 General

A new engine dynamometer test cell was constructed at ORF specifically for the purposes of engine testing under this program and other programs. The dynamometer used throughout the program was an existing General Electric eddy current type with a 381 kW absorption capacity at 5000 RPM. Due to the high inertia of the dyno, special driveshaft

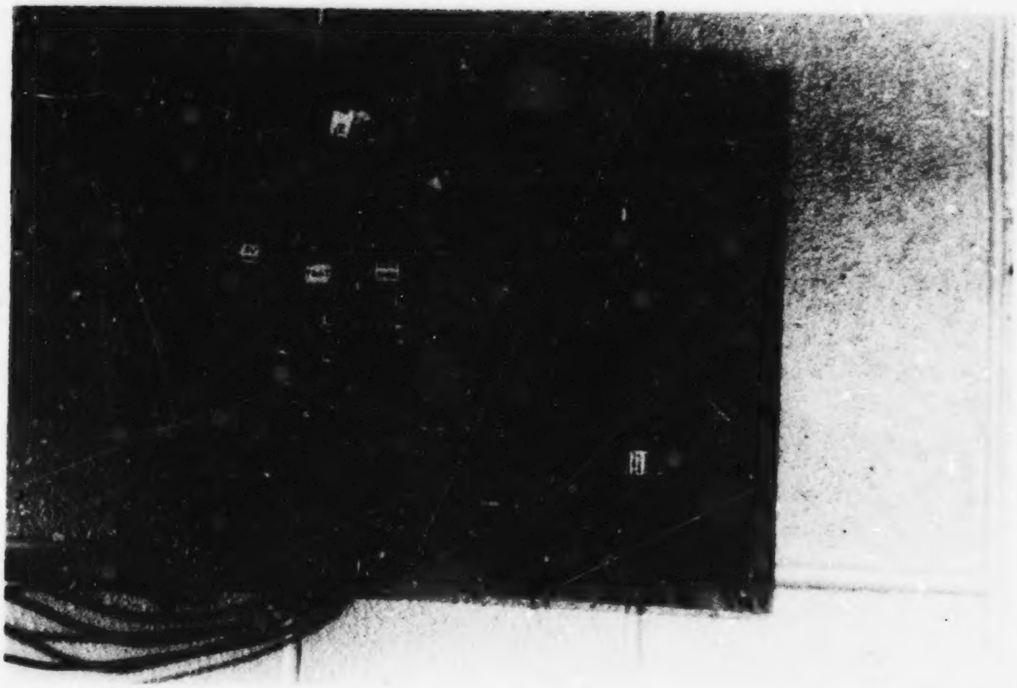

FIGURE 5 Methanol controller for a Methanol/Diesel emulsion fuel system.

and adapters were procured. The driveshaft incorporates rubber elements to absorb the high frequency output pulsation characteristics of a diesel engine. Utilizing a solid driveshaft may have led to a driveshaft failure.

The test engine was installed on a Clayton engine stand (supplied by ORF) and coupled to the dynamometer. Dynamometer load control problems were encountered during initial commissioning. These problems were related to the original dynamometer controller and a new silicon controlled rectifier controller was subsequently procured and installed. It became evident that the dynamometer supplier had sent the incorrect control unit. Several adjustments were made to the controller and it performed satisfactorily for the balance of the test program.

Several problems were encountered in obtaining the appropriate throttle actuator used to control the governor control lever. The first throttle actuator used (Barber-Coleman Plus 1) provided insufficient torque in order to overcome the considerable tension of the injection pump control lever spring. Two larger units were investigated (Plus 4 and Plus 6) prior to selecting the appropriate one. The Barber Coleman (Plus 6) actuator was installed directly on the engine and later changed to a remote location. Installation in the remote location was necessary to allow space for the hydraulic pump used in the emulsion tests.

Large capacity ventilation ductwork was installed in the test cell to handle the high airflow (12 m^3/min) requirements of the air-cooled engine. Dampers in the make-up air ventilation system allowed for some control of the cooling air temperature. Engine combustion air was supplied from outside of the test cell with appropriate filtration using a dry element air cleaner. The two exhaust banks from the engine were combined to a common 15 cm (6 inch) stainless steel tube. Engine exhaust could be routed directly outside the building or connected to the dilution tunnel used for emissions testing.

A 4,500 litre tank was used to store diesel fuel for the test engine. The fuel was supplied to the test cell by a pump via pressure relief valves, filters and fuel lines. Fuel consumption was measured real-time on a mass basis using a Flowtron (Model 10E) fuel flowmeter. Supply fuel to the engine was cooled using a tube and shell type heat exchanger. Entrained air in the fuel system could be removed using a vapour vent installed immediately after the heat exchanger. Return fuel flow from the injection pump was diverted back into the fuel loop upstream of the heat exchanger.

Type 'K' and type 'T' thermocouples were used to measure high (200°C to 2000°C) and low (0°C to 200°C) temperatures, respectively. Individual cylinder exhaust temperatures were monitored to provide an indication of cylinder-to-cylinder variations in temperature. Cylinder head temperature on number 4 cylinder was measured for an indication that sufficient cooling air flow was obtained. Lubrication oil, fuel, combustion air and cooling air temperatures were measured for a general indication of the test conditions. Combustion air temperature was also used in the calculation for correcting observed torque to corrected torque. Dynamometer (also engine) speed was measured using a 60 tooth gear and frequency pick-up located on the dynamometer. Two Viatran strain gauge type pressure transducers were used to measure fuel supply pressure and exhaust pressure.

6.2 Computer Control and Data Acquisition System

An existing Hewlett Packard computer control and data acquisition system was purchased by ORF to fulfill the test requirements for this program. The computer system is based on a HP 1000 mini-computer with 128K words of memory with an HP 7906 disk unit with 28 Mega Byte storage as the mass storage medium. All programs and data are stored on the disk. Operating system commands and certain system utilities are accessed from the system console. The input/output (I/O) subsystem is based on Computer Products Incorporated (CPI) I/O hardware. All 24 high level and 48 low level analog signals, along with 2 frequency inputs, are processed via the CPI I/O equipment. Three analog outputs for engine speed control, dynamometer control by speed and dynamometer control by torque are provided in this system. The operator console provides the test cell operator with the interface to the engine/dynamometer test system. A cathode ray tube (CRT) on the operator console displays all measured and calculated engine data for the test cell. Operator commands are entered via a keyboard on the operator's console.

During a test the computer system reads and corrects engine speed and load five times per second using a process control algorithm. The control algorithm contains 60 process control coefficients to allow for optimization of engine and dynamometer control relative to their individual characteristics such as inertia, speed response, engine governor, and control stability. The software incorporated in the computer system allows for the calibration of transducers, flowmeters, dynamometer and other analog inputs.

Transient engine tests are achieved by programming the appropriate test cycle into the schedule builder with definitions of required engine speed and torque at intervals as small as one second. Each entry of a required torque/speed condition constitutes one step with a total of 198 steps available in the schedule builder. Series of these steps can be identified as being a minor cycle which allows for repetitive testing of minor cycles. Further, the series of minor cycles can be incorporated into major cycles significantly expanding the length of the transient cycle. Up to eight relays can be activated or deactivated any particular step. These relays can be used to control such devices as EGR valve, sampling equipment, dampers, etc.

A test cell shutdown sequence can be activated by the computer system if a specific parameter has been exceeded. This capability provides for a considerable safety margin when testing engines. Up to fourteen user definable parameters can be identified by the test cell operator to either provide alarm or complete engine shutdown.

Reports of a complete transient test or a CRT screen mask can be provided via a Centronics printer.

7. COMBUSTION AND FUEL INJECTION STUDIES INSTRUMENTATION

7.1 General

The capability for utilizing methanol/diesel emulsions as a fuel in compression ignition engines depends largely on the ability of the engine to burn the fuel. Engines are designed to compromise the optimization of fuel consumption, power output, emissions and durability. The combustion characteristics of the fuel are, therefore, an indication of the relative flexibility of the engine to use off-specification fuels.

Cylinder pressure measurements have been used extensively to evaluate the combustion characteristics of various fuels. Ignition delay, rates of cylinder pressure rise and peak cylinder pressure are all variables that can effect the performance of the engine. High rates of cylinder pressure rise and peak cylinder pressures can lead to premature durability problems due to excessive stresses on the piston, connecting rod and crankshaft. Excessive ignition delay, on the other hand, can adversely affect the fuel consumption and emissions characteristics of the engine.

Cylinder pressures and fuel injection pressures were measured in this program to determine the effects of methanol/diesel utilization in a Deutz F8L-413 F/W engine. The following subsections describe the instrumentation that was used for these studies.

7.2 Cylinder Pressure Transducer

A miniature quartz pressure transducer (Model 111A22) and power supply were initially purchased from PCB Piezotronics Incorporated. Mounting of this transducer required the fabrication of a special glow plug adapter to allow for the cylinder pressure measurement inside the precombustion (swirl) chamber. The glow plug adapter incorporates tubes for the supply of cooling water. This assembly provides for easy installation since the transducer and adapter simply replace the standard Bosch glow plug. The glow plug adapter as initially received was not of the same size or profile as the standard glow plug. Modifications to the adapter were made by PCB so that the combustion characteristics would not be affected.

Following two hours of engine operation on neat diesel fuel the transducer failed. The transducer was returned to PCB Inc. where they identified the failure as distortion of the transducer diaphragm. PCB Inc. suggested that he distortion was due to overheating of the diaphragm. The transducer was repaired and returned to ORF. After only a few hours of engine operation the repaired transducer failed. Again PCB Inc. identified the failure was attributable to overheating and resulted in a distorted diaphragm which had separated from the transducer body. PCB repaired the transducer by installing a double diaphragm which was to provide increased strength and heat resistance. In spite of these latter modifications the unit failed again while operating the engine near full load condition.

Subsequent to the problem with the PCB equipment the transducer and all associated hardware was returned to PCB Inc. The program account was credited for the return of the equipment.

An AVL pressure transducer (Model 12 QP 505 clk) quartz pressure transducer was ordered to replace the PCB unit. The cylinder head (No. 1 cylinder) and liner were removed from the engine to machine both parts. Machining of the cylinder head was carried out according to specifications provided by KHD Germany. Figure 6 illustrates the location of the AVL transducer in the cylinder head. KHD Canada advised that the measurement of cylinder pressures in the pre-combustion chamber should be representative of the pressures in the main chamber.

The cylinder pressure transducer was calibrated with a dead weight tester prior to installation in the engine.

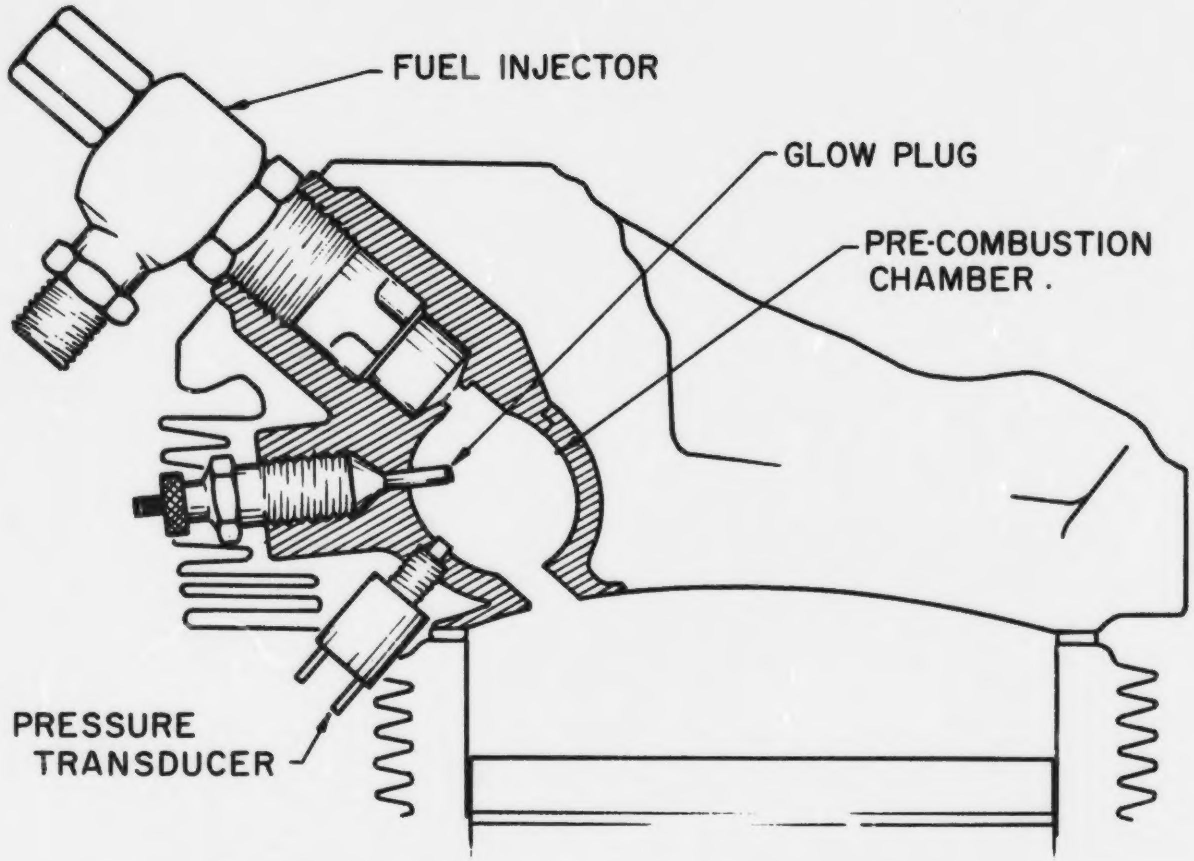
FUEL INJECTOR
GLOW PLUG
PRE-COMBUSTION CHAMBER.
PRESSURE TRANSDUCER

Figure 6: INSTALLATION OF CYLINDER PRESSURE TRANSDUCER

7.3 Fuel Pressure Transducer

An AVL strain gauge type pressure transducer (Model 31 DP 1200 E) was purchased for the measurement of fuel injection line pressures. A strain gauge signal conditioning unit (Model D1/E-20) was procured from Durham Instruments. The signal conditioning unit provided an exitation voltage to the bridge and amplified the output voltage from the bridge. Following calibration using a dead weight tester the transducer was installed in the No. 1 cylinder injection line close to the injector. A portion (80 mm) of the line length was removed to compensate for the initial volume of the transducer. Figure 7-A shows the installation of the pressure transducer in the fuel injection line.

7.4 Shaft Encoders

An optical shaft encoder was used to provide one pulse for every degree of crankshaft rotation. The encoder provided 720 trigger pulses per revolution and one marker pulse per revolution. Special brackets were installed on the engine so that the encoder would operate at one half crankshaft speed. This configuration provided 360 trigger pulses per revolution of the engine and one top dead centre (TDC) pulse at the beginning of every intake stroke.

Outputs from the crank angle encoder were connected to a digital waveform analyzer for processing of the signals. Figure 7-B shows the installation of the shaft encoders on the engine.

7.5 Norland Digital Waveform Analyzer

A Norland Model 3001, processing digital oscilloscope was used to display, process and store the waveforms obtained from the combustion and fuel injection, pressure transducers and the optical shaft encoders. This instrumentation consists of a floppy disk drive (Model 3702), keyboard, 3001/DMX mainframe and a oscilloscope screen (Model 3106R). Two analog input

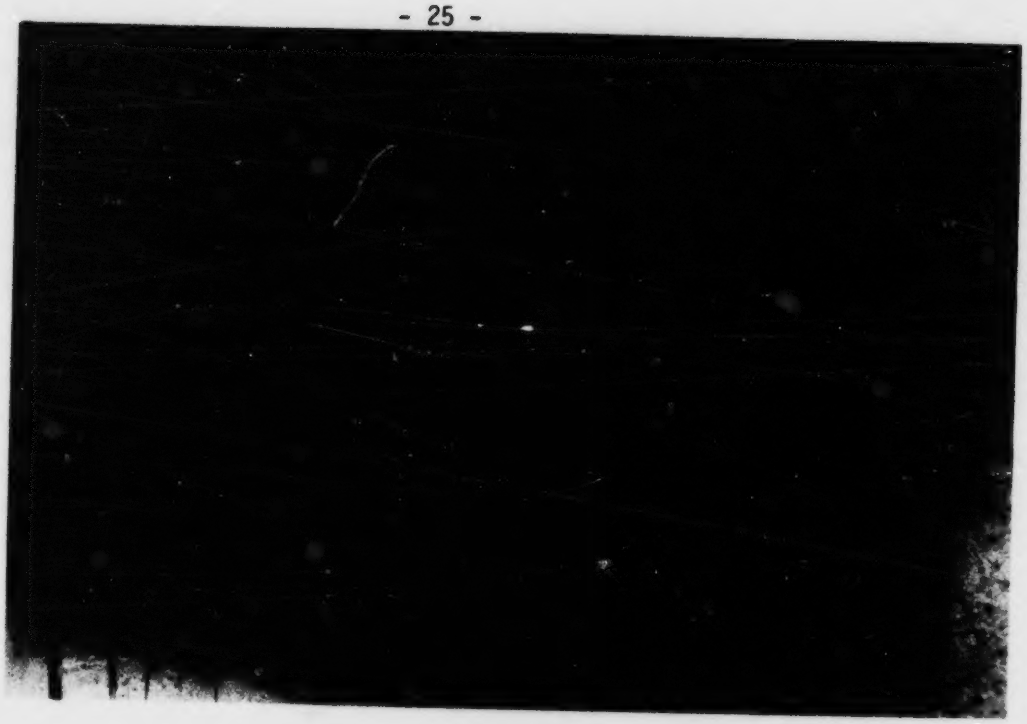

FIGURE 7-A

Installation of Pressure Transducer in Fuel Injection Line

FIGURE 7-B

Shaft Encoder Installation

channels were used; however, the unit can be expanded to accommodate up to 4 inputs. The analyzer section incorporates a signal averager which allows averaging of any number of sampled waveforms. Mathematical calculations of the waveform, such as integration and differentiation, can be quickly achieved with keyboard commands. Processed information can be stored in registers for subsequent data storage on a 13.3 cm (5σ") floppy disk. Keyboard commands can also be sequenced into a program format and stored on disk for future use. Figure 8 shows the Norland equipment.

A program was written to display the cylinder volume (V) versus crankshaft position (Θ). This program required the entering of the Deutz 413 series engine geometry. The waveform was differentiated to obtain a separate waveform:

$\frac{dV}{d\Theta}$ the rate of change of cylinder volume versus crank angle

Both waveforms were identified and stored on disk to be recalled later for combustion and fuel injection analysis.

A separate program was written to acquire combustion pressure and fuel injection pressure data. The program prompts the Norland analyzer to sample 40 consecutive combustion and fuel injection cycles. Waveforms are averaged and the resultant waveform displayed on the CRT. There are several 'pause' statements in the program to allow the operator the task of inspecting waveforms and recording of waveform values.

The following information was obtained for the analysis of combustion and fuel injection characteristics.

FIGURE 8 Norland digital waveform analyzer.

P_{max} - maximum cylinder pressure
$CA^{o}\ P_{max}$ - crankangle for P_{max}
ΔP_{max} - maximum rate of change of cylinder pressure rise with respect
$CA^{o} \Delta P_{max}$ - to crankangle
$CA^{o}\ P_{max}$ - crankangle for P_{max}
INJ_{Begin} - location for commencement of fuel injection in crankangle degrees
$INJP_{max}$ - location for rise of fuel injection line pressure in crankangle degrees.

8. EMISSIONS TESTING EQUIPMENT

8.1 Heavy Duty Diesel Emissions Test Facility

The sampling and measurement of diesel exhaust emissions has presented many problems with respect to obtaining representative data that will correlate to conditions that occur in the underground mining environment. Chemical and physical reactions with certain species of diesel exhaust emissions take place after the exhaust has been released from the engine exhaust system. Specifically, particulate agglomeration in the soluble and insoluble form occur as the exhaust temperature is lowered to promote condensation of the soluble organic material. Formation of nitrogen dioxide (NO_2) from nitric oxide (NO) is also a characteristic reaction in diesel exhaust as it is released from the exhaust system. These reactions have necessitated the need for a representative diesel exhaust sampling and analysis system. EPA has standardized such a system for engine certification procedures.

In an effort to keep abreast of these changes, ORF has installed and commissioned a heavy duty diesel emissions test facility. The primary purpose of this facility is the measurement of emissions from diesel engines which are part of the dynamic test facility (Figure 9). The purchase of this system was

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cost shared between ORF and the Ontario Ministry of Labour. The facility is comprised of two major systems; the dilution tunnel system and the analytical system. The following subsections describe these systems.

8.2 Dilution Tunnel System

There are basically two types of dilution tunnels available for the sampling of diesel exhaust emissions. One uses a single dilution method, the other a double dilution. ORF has selected a double dilution tunnel from a flexibility and cost standpoint. With a double dilution system the primary air mover can be down-sized considerably to meet the temperature criteria necessary in designing such a system. The system comprises of three basic sections as described below.

8.3 Dilution Tunnel

The dilution tunnel consists of 25.4 cm inside diameter primary tunnel and a 10.2 cm inside diameter secondary tunnel. All tunnel components are fabricated of stainless steel. Engine exhaust enters the primary tunnel via an upstream facing 10.2 cm nozzle. Dilution air flows past the nozzle and the resultant counter-current flow enhances mixing of the exhaust with the air. The primary tunnel has been engineered to provide a Reynolds number of more than 4000 to provide sufficient turbulence of the diluted exhaust. A fine mesh screen prevents large foreign objects from entering the primary tunnel.

Three sample probes are located approximately 2.5 meters downstream of the exhaust inlet. The first probe is used to transfer a portion of the primary tunnel exhaust to the secondary tunnel. The second probe is used for sample transport to the heated hydrocarbon analyzer and the third probe is dedicated to the other gaseous analyzers. Maximum allowable primary tunnel gas temperature at the sample probes is 190°C. A specially designed acoustic chamber was installed at the primary tunnel inlet to minimize engine exhaust and air mover noise in the vicinity of the test facility.

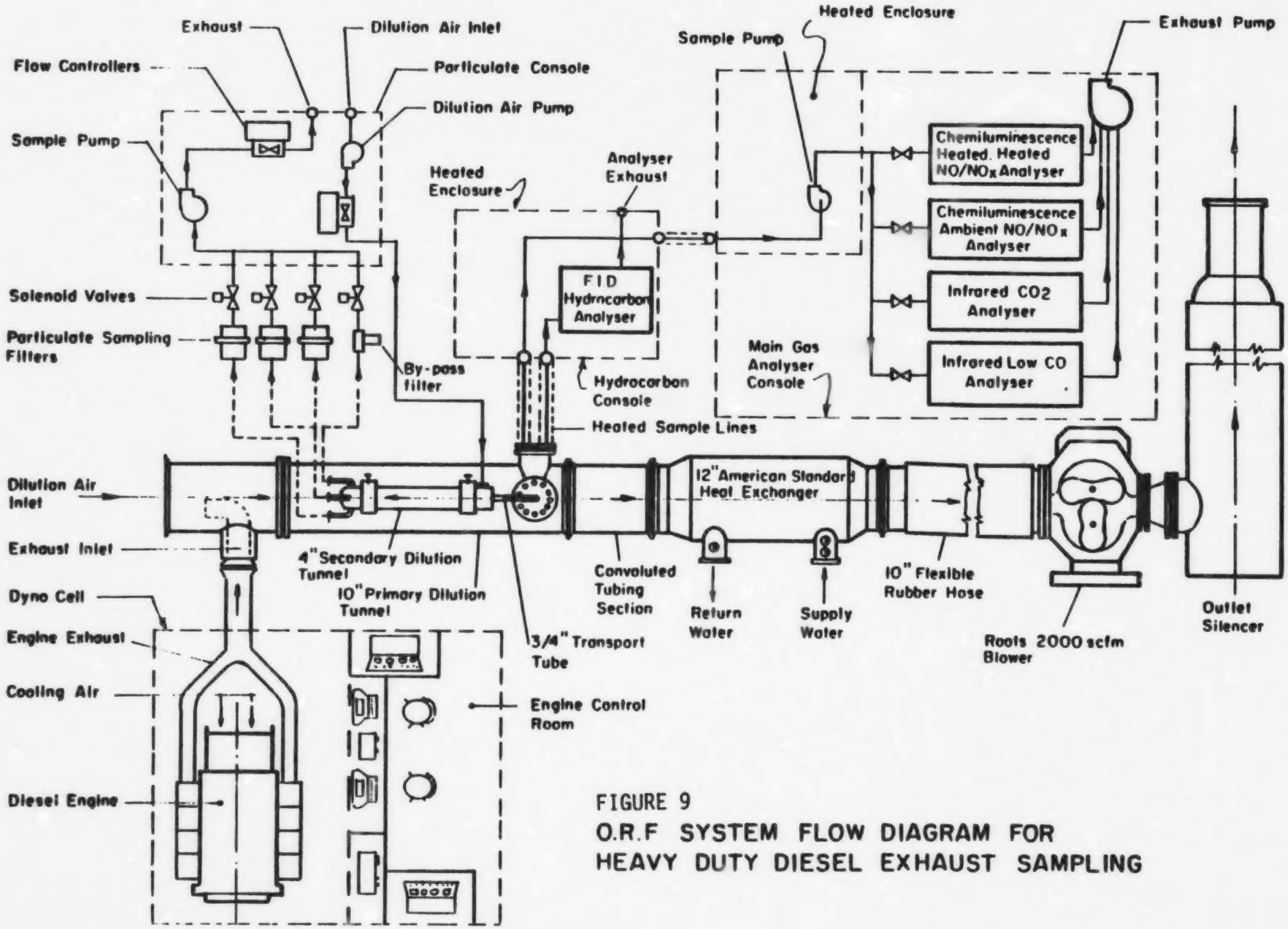
Exhaust
Dilution Air Inlet
Flow Controllers
Particulate Console
Dilution Air Pump
Sample Pump
Solenoid Valves
Particulate Sampling Filters
By-pass filter
Heated Enclosure
Analyser Exhaust
FID Hydrocarbon Analyser
Hydrocarbon Console
Heated Sample Lines
Sample Pump
Heated Enclosure
Main Gas Analyser Console
Exhaust Pump
Chemiluminescence Heated. Heated NO/NOx Analyser
Chemiluminescence Ambient NO/NOx Analyser
Infrared CO2 Analyser
Infrared Low CO Analyser
Dilution Air Inlet
Exhaust Inlet
4" Secondary Dilution Tunnel
10" Primary Dilution Tunnel
3/4" Transport Tube
Convoluted Tubing Section
12" American Standard Heat Exchanger
Return Water
Supply Water
10" Flexible Rubber Hose
Roots 2000 scfm Blower
Outlet Silencer
Dyno Cell
Engine Exhaust
Cooling Air
Diesel Engine
Engine Control Room

FIGURE 9
O.R.F SYSTEM FLOW DIAGRAM FOR
HEAVY DUTY DIESEL EXHAUST SAMPLING

The secondary tunnel can be used to further dilute the sample from the primary tunnel to maintain a sample filter that will not exceed the maximum allowable 52°C. Three sample filters and one bypass filter are connected to the outlet of the secondary tunnel. The filter holders accept 70 mm diameter filters (Pallflex T60A20) and produce a 60 mm diameter stain area.

Secondary, or back-up filters, are used to remove any particulate material that has passed the primary filter. Any one of the four filters can be selected manually or automatically from the particulate console. Automatic sequencing of the filter is achieved using computer activated relays or using a programmable sequence timer.

The particulate console, contains an air pump and protective filters for sampling diluted exhaust. A second pump is used to provide pre-filtered air to the secondary tunnel when further dilution is required. Mass flows of sample gas and secondary dilution air are measured and controlled using mass flow controllers (Tylan Model FC202). These controllers are state-of-the-art devices which continuously monitor and correct the mass flow to maintain a proportional sampling rate, regardless of gas temperature and pressure. Accumulated dilution and sample gas flows are displayed using integrators, one set for each of the sample filters. The particulate console also contains a temperature measuring device to allow for recording of a variety of temperature stations, especially the primary and secondary tunnel gas temperatures.

8.4 Heat Exchanger

According to EPA specifications, the primary tunnel gas temperature must be adjusted to 43°C in order to provide constant gas density conditions to the primary air mover. In order to achieve a 147°C gas temperature drop, a shell and tube heat exchanger is located between the primary dilution tunnel and air mover. A 227 Lpm water pump recirculates water through the shell side of the heat exchanger while primary tunnel exhaust gas is passed through the tube side.

During testing of duty cycles with high load factors, the primary tunnel gas temperature is well above 43°C. In these cases the heat exchanger is used solely to cool the gas and this is achieved by adding cold water to the recirculating water loop. Thermostatically controlled, air actuated, water valves allow water to enter the system and a check valve discharges an equal volume of warm water. A second heat exchanger, which is steam heated, can be used to raise the water temperature to 43°C (in the case of low load factor duty cycles).

8.5 Air Mover

The primary tunnel gas flow is normally maintained at 51.0 standard cubic meters per minute (SCMM) with a high capacity positive displacement blower. This blower is a Roots type and uses a 22 kW electric motor as a drive. Excessive noise, characteristics of these blowers, is reduced using a Donaldson muffler.

8.6 Gas Analysis

The gas analysis system is comprised of a hydrocarbon console and a main analysis console. Filters, housed in the heated hydrocarbon console, are used to remove particulate matter from the sample gas stream. A Beckman, Model 402, heated hydrocarbon analyzer continuously measures gaseous hydrocarbons (as methane) at a temperature of 190°C using a flame ionization detector. Background (ambient air) hydrocarbon concentrations are determined by sampling the dilution air at the primary tunnel. Concentrations of hydrocarbons in the dilution air are subtracted from the primary tunnel concentration to obtain hydrocarbon concentrations that are attributable to engine exhaust.

The main analysis console contains the NO, CO, CO_2 and heated NO_x analyzers. Two sample pumps are used to provide sample gas to the various analyzers. The following analyzers are used:

NO_x - Beckman Model 955 heated chemiluminescent analyzer
NO - Beckman Model 951A chemiluminescent analyzer
CO - Beckman Model 867 non-dispersive infra-red
CO_2 - Beckman Model 864 non-dispersive infra-red.

Three calibration gases are used to span each analyzer for a given concentration range. These gases can be selected by push buttons on the main analysis console front panel. Strip chart recorders are used to display analyzer outputs on a continuous basis. Heated lines are used to keep the sample temperature well above the gas dewpoint to minimize losses due to condensation. A Hankinson dryer is used, however, to remove sample gas moisture prior to the NO, CO and CO_2 analyzers to prevent water interference in the analysis and damage to the instrument.

The voltage outputs from the emissions analyzers are connected with the test cell computer control equipment. Analyzer calibration curves are entered into a software subroutine and thus allows for conversion of analyzer output voltage to engineering units (i.e. ppm or %). Appropriate calibration values for the dilution tunnel air mover are also entered (i.e. temperature, pressure, humidity) for the calculation of pollutant mass emission rates. These mass emission rates are displayed as fuel specific, engine power specific and time specific units.

Each of the exhaust gas analyzers has a different response time to a step change in gas concentration. For this reason, a separate software utility is used to compensate for the variations in analyzer lag times. This compensation allows for transient engine testing with appropriate corrections for exhaust pollutant emission values to the load and/or speed changes of the engine.

8.7 Aldehydes Sampling Equipment and Analytical Procedures

It is well known that aldehydes are produced from the combustion of diesel fuel in a compression ignition engine. Some of the lower molecular weight aldehydes such as formaldehyde and acetaldehyde have reported toxicities. In addition, increasing concerns have been expressed over the presence of formaldehyde in the environment because of its possible carcinogenicity. For these reasons, it was felt that the emissions of aldehydes from a methanol/diesel emulsion fueled engine be characterized and compared to that from the same engine fueled with diesel.

A special sampling train was developed for the collection of dilute engine exhaust from the primary dilution tunnel. The sampling train consists of a heated sample line, filter, impingers and a pump with a calibrated dry gas meter.

Carbonyls present in the diluted engine exhaust are bubbled through a saturated solution of 2,4-dinitrophenylhydrazone (DNPH) at a rate of 4L/minute. These carbonyls react with the DNPH reagent to form carbonyl DNPH derivatives which are insoluble in water. Subsequent to sample collection in the impingers the solutions are transferred to sample containers. Carbonyl hydrazone derivatives and diesel particulates are separated by filtration and the filtered material washed with methylene chloride. The filtrate is extracted with pentane to isolate the soluble derivatives. Methylene chloride and pentane extracts are combined and dried over anhydrous sodium sulphate. The extracts are then concentrated to a volume of 5 mL in methylene chloride in Kuderna Danish evaporators and taken to dryness with a flow of dry nitrogen at room air temperature. The samples are then brought to a volume of 10 mL with a solution of acetonitrite containing a benzophenone internal standard.

The samples were analyzed by high performance liquid chromatography (HPLC) to determine quantitatively and qualitatively the following aldehyde compounds:

formaldehyde
acetaldehyde
acetone
crotonaldehyde
methyethyl ketone and iso butraldehyde
benzaldehyde
hexaldehyde

A C_{18} RP, Ultrasphere ODS column was used for the separation of the individual aldehyde components utilizing CH_3CN and H_2O in a solvent programmed run. The eight carbonyl compounds were derivatized with 2,4-DNPH and used as a reference standard for the quantitative determinations. An ultra violet detector, set at 365 nm, was used for the detection of the compounds. The peak area of each carbonyl DNPH in the sample was corrected for interferences determined in the method blank. Also, the recovery of the carbonyl DNPH from the reagent solution was determined by the analysis of a fortified sample. Mass concentrations of the individual carbonyl compounds in the samples was determined using the following calculation:

$$\mu g \text{ of carbonyl DNPH} = B \times C_{15} \times \frac{A_c}{A_{15}} \times V$$

where B = recovery correction factor
C_{15} = concentration of internal standard in µg/mL
A_c = area of compound peak in sample
A_{15} = area of internal standard peak in sample
V = volume of sample µL

The exhaust concentration of the aldehyde compounds were calculated by correcting the sample gas volume to standard conditions and tunnel dilution ratio.

9. DEVELOPMENT OF AN LHD CYCLE

9.1 Underground Engine Testing

Testing was conducted at Falconbridge's Lockerby Mine in Sudbury, Ontario to determine a scoop tram engine's operating conditions under load-haul-dump (LHD) cycles since a suitable machine was not available at INCO. All measurements were made on a Jarvis Clark JS-500 scoop tram equipped with a Deutz F8L-413 F/W diesel engine. The fuel injection pump was modified by Henninger Diesel (Sudbury) to operate with an RSV governor. Henninger alters the governors in order to improve the engine torque characteristics below 1500 RPM. Typical characteristics for the pump with an RSV governor are as follows:

High Idle Speed	2050 RPM
Rated Speed	2000 RPM
Speed Droop	2.5%
Fuel Delivery at Rated	≃76 cc/1000 at 8.8 mm
Fuel Delivery at 1400 RPM	≃79 cc/1000 at 9.5 mm
Fuel Delivery at 1200 RPM	≃81 cc/1000 at 10.0 mm

Falconbridge sent the fuel injection pump to ORF for fitting of a linear displacement transducer (LDT). The transducer, Trans-teck Model 244-000 was mounted on the pump while the transducer extension rod was connected to the injection pump control rod. A special voltage regulator was built to control the transducer input voltage to 8.0 vdc. The transducer output was set to 100 mvdc full scale.

A mechanical frequency generator and a frequency to voltage converter was purchased from Ruhl Machinery (Toronto). The frequency generator was connected to the engine tachometer drive fitting and the converter maximum voltage set to 100 mvdc. Outputs of both the LDT and speed converter were recorded on Hewlett Packard strip chart recorders. These recorders were powered by the scoop tram 12 volt electrical system. Chart speed was set to 1 mm/sec.

All testing was conducted at the 2900 foot level of the Lockerby Mine. The following are conditions to which the scoop tram was required to operate (all measurements are approximate):

o	drift to muck pile (stope)	80 ft (24 m)
o	stope gradient (drift to muck)	20°
o	drift to ore pass	90 ft (27 m)
o	drift gradient	0

An 80° turn was required approximately 60 feet (18 m) into the drift to enter the ore pass. This turn forced the operator to slow the scoop tram on his return from the ore pass.

A total of 15 LHD cycles were measured. The first cycles were not used in data analysis since these cycles were used to familiarize the operator to the conditions and allowed ORF personnel time to make adjustments to the instrumentation. The LHD cycle was defined into 6 segments as follows:

- run up stope
- mucking
- back out of stope
- haul
- dump
- backup from dump

Times were measured and recorded for scoop tram operation in each segment of the cycle.

9.2 Data Analysis

9.2.1 Underground Tests

Recorder chart traces were reviewed and each segment of each cycle identified on both the speed and rack position charts. Using a polar planimeter, the area under the curve was determined, and with the use of a scaling factor the average speed and rack position calculated for each segment.

Table 2 gives a breakdown of time in each segment. Averaging the times in each segment it was found that the average LHD cycle lasted for 207 seconds. Of this total 13.5% of the time was spent for running up the stope and backing out of the stope each for a total of 27.0%. Mucking accounted for 37.2% of the time, hauling 14.5%, dumping 6.3%, and the backup from dump 15.0%. Actual mucking times varied between 26 and 125 seconds with an average of 77 seconds. It was noted that during most mucking segments the operator backed out from the pile and returned to the pile in order to break up the muck pile. With the exception of mucking operations, all other segments of the cycle were consistent from a time in segment viewpoint.

Table 3 gives average rack position and speed data for the first 6 cycles (4 to 9) for each segment of the cycle. Run up the stope showed an average rack of 7.5 mm and speed of 1983 RPM and mucking 7.4 mm and 1759 RPM rack and speed, respectively. Rack position decreased to 6.2 mm and speed increased to 2021 RPM for back out of stope since the tram was travelling down the stope gradient. The haul segment accounted for 7.4 mm of rack and engine speed of 1986 RPM. A 6.4 mm rack and engine speed of 2015 RPM was noted for the dump segment. Rack position as well as engine speed decreased to 6.3 mm and 1967 RPM, respectively, for the backup from dump segment. As mentioned previously speed was reduced during back-up to negotiate the 80° turn. Rack position was lower due to the machine tramming empty.

Table 4 gives load factors for each segment and includes the average overall load factor of 69%.

9.2.2 Computerized Simulation Tests

Exact simulation of field conditions on an engine dynamometer is impossible. Rapid engine transients imposed by activation of the tram hydraulics are difficult to duplicate. However, the general transients (including sharp rack peaks) can be accommodated with the use of a computer controller system. Table 6 gives results of engine speed, rack position, actual torque, maximum available torque and percentage of maximum torque available for each one second interval of the simulated test cycle. Table 5 gives the average values for Table 6 and shows the average load factor for the simulated cycle to be 67%. This load factor and the individual segment load factors can be altered by changing setpoints in the schedule builder.

10. COMBUSTION STUDIES TEST SCHEDULE

10.1 Standard and Advanced Timings

Measurements of cylinder pressure and fuel injection line pressure were taken at steady state engine conditions for baseline diesel fuel (No. 1 Gulf Diesel 40) and methanol/diesel emulsion. A comprehensive test matrix of 30 engine speed/load conditions was used to establish baseline engine conditions at 14^o BTDC static injection timing. Results from these tests provide information to prepare characteristic combustion pressure curves for the Deutz F8L 413 F/W engine. A condensed text matrix of 16 engine speed/load conditions was used to measure combustion and injection characteristics at static injection timing settings of 17^o BTDC and 20^o BTDC for engine operation on diesel fuel. The condensed test matrix included load conditions of 100, 75, 50, 25 and 10 percent at rated speed (2300 RPM), intermediate speed (1900 RPM) and peak torque speed (1500 RPM). Pressures were also measured at engine idle condition (700 RPM) with a parasitic dyno load of approximately 30 Nm. Diesel fuel consumption rates were measured for all test conditions.

Combustion and injection pressures were measured over the 15 speed/load condition test matrix for engine operation on 12% (E/E)) methanol/diesel emulsion (24% on a mass basis). Engine conditions were allowed to stabilize prior to the sampling of 40 combustion and injection cycles. Samples of the emulsion fuel were taken at each condition to ensure that the appropriate ratio of methanol to diesel was being provided to the engine. Tests were conducted at standard static injection timing of 14^{o} BTDC and advanced timings of 17^{o} BTDC and 20^{o} BTDC. It was suspected that testing with emulsion at the advanced timing settings would compensate or limit the ignition delay characteristics with methanol/diesel emulsion.

Additional tests were performed at the three (14^{o}, 17^{o}, 20^{o} BTDC) injection timing settings with 12% (E/E) methanol/diesel emulsion and using glow plug heat. Total current draw for the eight (8) glow plugs was approximately 35 amps at a voltage of 8VDC. This results in a power level of 35 watts per cylinder. As in the case of advanced timing settings, it was expected that glow plug heat would lessen the ignition delay created by the methanol/diesel emulsion.

A limited number of tests were conducted at 2300 RPM engine condition (17^{o} timing) with 15% (E/E) methanol/diesel emulsion (30% on a mass basis) with and without glow plug heat assist. Obvious unstable engine operation, prevented further tests with this fuel.

10.2 Ignition Improved Emulsion

Fuel consumption results from the 12% (E/E) methanol/diesel emulsion tests showed that the emulsion increased the fuel energy consumption of the engine at a given speed/load condition. This characteristic results in a degradation of the thermodynamic efficiency of the engine, primarily caused by ignition delay. Attempts in reducing ignition delay by advancing injection timing and utilizing glow plug heat were unsuccessful.

It was decided to test a commercially available, diesel fuel ignition improver in the emulsion to minimize ignition delay and increase the diesel substitution from 12% to 15% on an energy basis. A diesel ignition improver, produced by Ethyl Corporation, was selected for these tests. The improver, identified as DII-3, is an ocytl nitrate base solution normally used for enhancing the cetane number of lower grade diesel fuel. Specifications for the ignition improver are given in Table 7.

Tests were carried out with three different concentrations of the ignition improver in methanol (5%, 10% and 15% on a volume basis). These levels result in emulsion concentrations of 1.5%, 3.0% and 4.5%, respectively, based on a 15% (E/E) methanol/diesel emulsion. All tests with ignition improved emulsion were carried out at a static injection timing setting of 14° BTDC. The 14° timing setting was selected on the basis of minimizing peak cylinder pressures and rates of pressure rise.

11. EMISSION STUDIES TEST SCHEDULE

Emissions tests were carried out for steady state engine conditions and the MTU-LHD cycle with and without methanol/diesel emulsion. Number 1 diesel fuel was used for the baseline tests and 15% (E/E) methanol/diesel emulsion for the emulsion tests. Octyl nitrate ignition improver (Ethyl DII-3) was blended with the methanol to provide an ignition improver concentration of 2.4% (V/V) in the emulsion. This concentration was selected on the basis that acceptable combustion and BSEC characteristics could be achieved with minimal incremental fuel cost increase. All emulsion emission tests were carried out with this level of ignition improver.

The following subsections describe the test sequences and procedures used for emissions testing.

11.1 Steady State Testing for Particulate and Gaseous Emissions Sampling

A test matrix of twelve (12) steady state load speed conditions was used to characterize particulate and gaseous emissions on neat diesel fuel and methanol/diesel emulsion. The test matrix is as follows:

Engine Speed RPM	Engine Load kW	Load % of Maximum
2300	139	100
2300	103	75
2300	69	50
2300	35	25
1900	122	100
1900	91	75
1900	61	50
1900	31	25
1500	103	100
1500	77	75
1500	52	50
1500	26	25

This matrix incorporates rated speed (2300 RPM) and rated torque (1500) conditions and the intermediate speed condition of 1900 RPM.

Particulate samples were taken from the dilution tunnel following stabilization of engine parameters at the load/speed condition. Samples were collected over a period of approximately 20 to 30 minutes.

Gaseous emissions of carbon monoxide (CO), carbon dioxide (CO_2), total hydrocarbons (THC), nitric oxide (NO) and nitrogen dioxide (NO_2) were measured from the primary dilution tunnel at each of the twelve (12) steady state engine conditions. Engine parameters were allowed to stabilize prior to collecting the data.

11.2 Steady State Testing For Aldehydes

A test matrix of six steady state load/speed conditions was selected to determine the effects of methanol/diesel emulsion on the aldehyde emissions. The test matrix used was as follows:

Engine Speed RPM	Engine Load kW	Load % of Maximum
2300	103	75
2300	69	50
2300	35	25
1900	91	75
1900	61	50
1900	31	25

Only six load/speeds were selected on the basis of the high cost for aldehydes analysis. It was felt, however, that these test conditions would provide for a reasonable indication of the effects of methanol/diesel emulsion on the aldehydes emulsions.

11.3 Transient MTU-LHD Cycle

Section 9 of this report describes, in detail, the development of a load-haul-dump cycle for a Jarvis Clark JS-500 LHD vehicle. This cycle was developed with the understanding that it be used to evaluate the impact of methanol/diesel emulsion on the engine performance and emissions.

Following the development of the cycle, it was discovered that the fuel injection pump rating specifications would not be suitable for INCO mining operations. Rated speed condition for the Deutz engines is 2300 RPM at the INCO mines whereas the Falconbridge mine set the rated speed to 2000 RPM. It has been suggested that this reduction in rated speed will decrease the maximum tramming speed of the mine vehicle.

It was decided, therefore, to utilize the MTU-LHD cycle (developed by John Johnson and Associates of Michigan Technological University) for the emissions test work under this contract. This cycle was derived from a Wagner ST-5 vehicle operating in a copper mine. A Deutz F8L 714 engine was used for the cycle development, and rated speed was set at 2300 RPM.

The MTU-LHD cycle is divided into four modes as follows:

Mode 1 - Driving into the drift from a cross-cut.

Mode 2 - Loading at the face (mucking).

Mode 3 - Hauling out of the drift from face of cross-cut.

Mode 4 - Hauling from cross-cut to dump point, dumping, and tramming to cross-cut from dump point.

The LHD cycle provided by MTU was programmed into the computer schedule builder for engine dynamometer cycle simulation. The resultant computer simulated MTU-LHD cycle provided an average load factor of 59%. Average engine conditions for each of the four modes of the cycle are given below.

Mode	Average Engine Speed RPM	Average Torque Nm	Average Engine Load kW	% Time in Mode
1	2339	234	57.3	18.0
2	1571	429	70.6	20.7
3	2187	364	83.4	20.7
4	2341	277	67.9	40.7

The average engine conditions for the complete MTU-LHD cycle were 2150 RPM and 311 Nm torque. Appendix C gives the average engine conditions for the complete cycle and also gives a second by second engine parameter listing for each second of the 150 second cycle.

The MTU-LHD cycle was used for all transient emissions and performance tests with methanol/diesel emulsion and neat diesel.

11.4 LHD Cycle Testing for Particulate and Gaseous Emissions

Engine exhaust gaseous emissions were measured and particulate samples taken during the MTU-LHD cycle for engine operation with and without methanol/diesel emulsion. The engine was allowed to operate over at least three (3) cycles prior to the recording of data and/or the collection of samples. Gaseous emissions were recorded for each second of the 150 second cycle and then averaged for the complete cycle. Particulate samples were collected over a number of consecutive cycles to obtain sufficient material for analysis.

The methanol controller was used to proportion the amount of methanol during the cycle relative to the amount of diesel fuel consumed. Emulsion samples were taken periodically during the tests to ensure that 15% (E/E) methanol/diesel emulsion was present.

12. TEST RESULTS

The following subsections give the test results for combustion studies and emissions studies with engine operation on diesel and methanol/diesel emulsion under various test and operating conditions. Combustion studies results are presented for three static injection timing settings and methanol/diesel emulsion with and without ignition improver. Emissions results are presented for steady state and transient engine testing with and without methanol/diesel emulsion. All transient emissions tests were carried out with ignition improved 15% (E/E) methanol/diesel emulsion.

12.1 Cylinder Pressure Measurement

12.1.1 Standard Static Injection Timing

Results of cylinder pressure tests for 14° static injection timing and engine operation on diesel fuel are presented in Table 8. The maximum cylinder pressure (P_{max}) increases with decreasing engine speed with maximums for a given speed generally between 25% and 75% load. Maximum P_{max} was recorded at 7490 kPa and is below the manufacturers limit of 10,000 kPa. Locations for P_{max} were found to be load dependent ranging from 363 crank angle degrees (CA^{o}) at light load to 370 CA^{o} at full load.

Maximum rates of change of pressure rise (ΔP_{max}) generally increase slightly as load decreases for a given engine speed. The highest ΔP_{max} recorded of 521 kPa/CA^{o} is well below the manufacturer's recommended upper limit of 1,000 kPa/CA^{o}. Locations of ΔP_{max} are between 360 CA^{o} (TDC) and 363 CA^{o} and are not as load or speed dependent as the location for P_{max}.

With application of 12% (E/E) methanol/diesel emulsion at standard timing (14°) and 2300 RPM the P_{max} levels increase by approximately 3% to 4% at 50, 75 and 100% load. A 13% increase in P_{max} occurs at 25% load. Table 9 gives the combustion data for the 15 speed/load conditions. Location of P_{max} advanced at 2300 RPM/100% and 75% load and retarded significantly at 25% and 10% load. Ignition delay is quite evident for these test conditions as observed by the retard of ΔP_{max} from 2 CA^{o} at high load to 8 CA^{o} at 10% load. This characteristic results from the application of methanol to the fuel. Figure 10 illustrates the

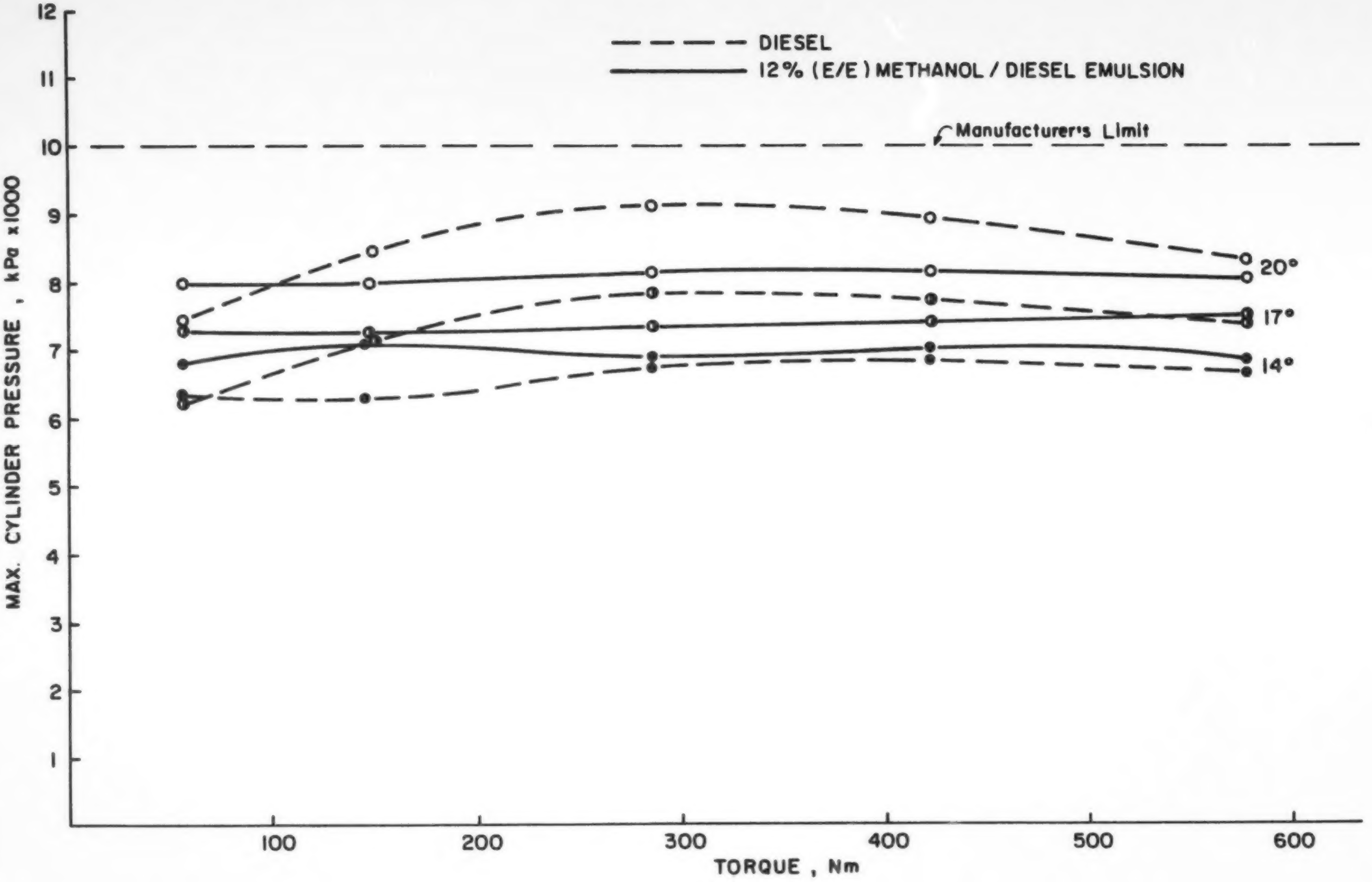

FIGURE 10: MAXIMUM CYLINDER PRESSURES FOR 2300 RPM CONDITIONS.

relationship of P_{max} versus load and injection timing at 2300 RPM for three static injection timing settings of 14, 17 and 20^o BTDC with and without application of 12% (E/E) methanol/diesel emulsion. The relationship of ΔP_{max} for the same test conditions is given in Figure 11.

Application of 12% (E/E) methanol/diesel emulsion at 1900 RPM engine conditions (14^o static timing) results in an increase in P_{max} by approximately 8% relative to operation on diesel fuel. Figure 12 shows that P_{max} is highest (7500 kPa) at 75% load for these test conditions. The location of P_{max} shifts 5 CA^o (retard) at 10% load and is essentially the same for the other 4 speed/load conditions with emulsion fuelling. Decreases in ΔP_{max} are observed at 75% and 100% load (1900 RPM) with emulsion, increase at 50% load and approximately the same values for 25% and 10% load. Location of ΔP_{max} was retarded by 1 to 3 CA^o relative to operation on diesel fuel and is not as severe as observed for some of the 2300 RPM test conditions.

Maximum cylinder pressures increased by 3% to 4% (25, 50, 75 and 100% load) and 7% at 9% load for engine fuelling with 12% methanol/diesel emulsion at the 1900 RPM conditions (14^o static timing). The highest P_{max} (6,600 kPa) occurs at the 50% and 75% load conditions. Locations of P_{max} did not change significantly with application of emulsion with the exception of the 9% load condition where 5 CA^o of retard was found. Increases of approximately 25% in P_{max} were found at loads of 50% and higher. An increase of 18% in P_{max} occurs at 25% load and a decrease of 38% at 8% load. Locations of P_{max} retards by 1 to 3 CA^o for the emulsion fuel at 1500 RPM conditions. Figure 13 illustrates the P_{max} trends for the 1500 RPM engine conditions.

Table 10 gives the test results for application of glow plug heat (35 watts per cylinder) during engine fuelling with 12% (E/E) methanol/diesel emulsion at standard injection timing. These results suggest that the addition of a limited auxiliary heat source has minimal effects in

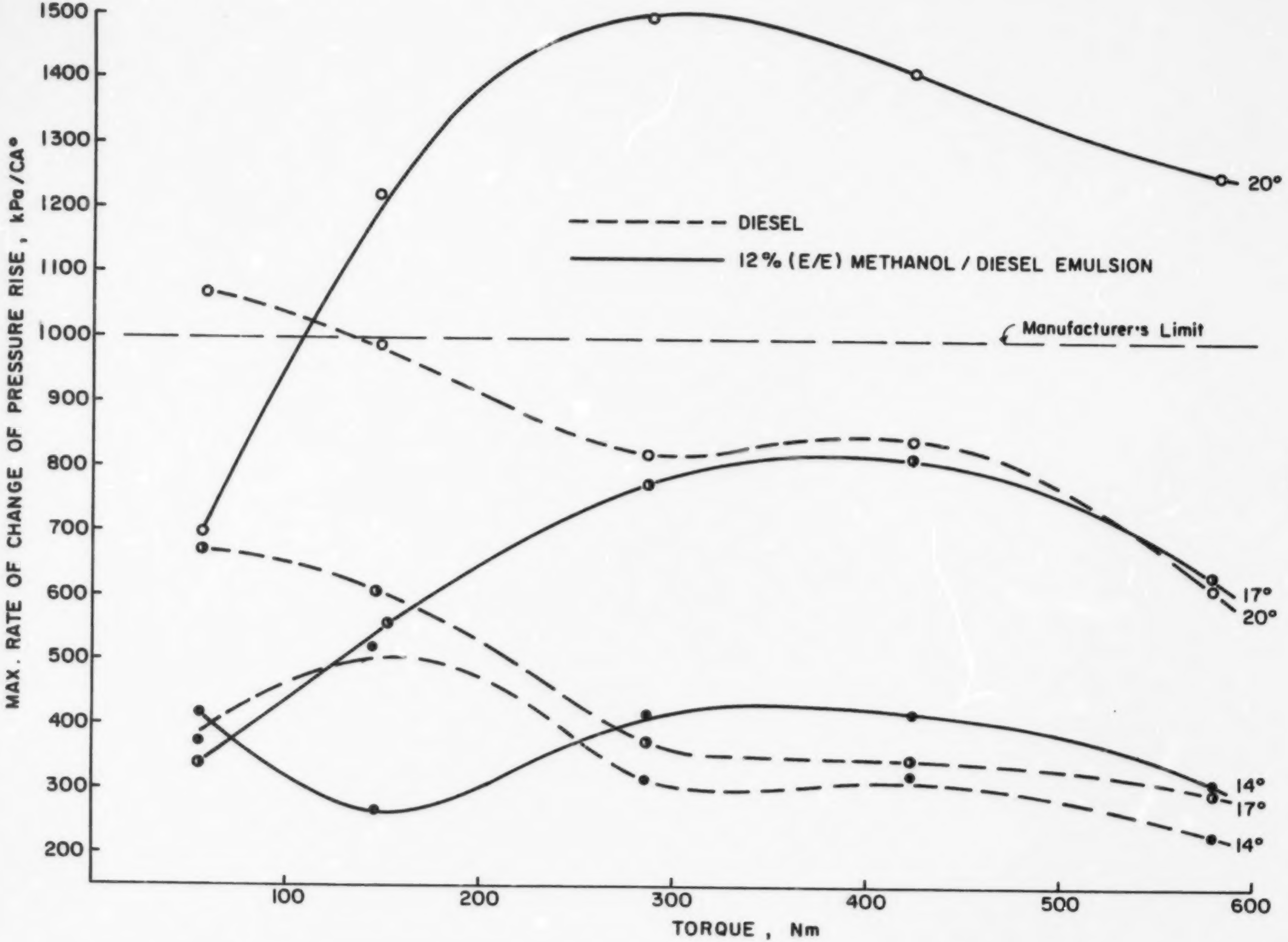

FIGURE 11: MAXIMUM RATE OF CYLINDER PRESSURE RISE FOR 2300RPM CONDITIONS

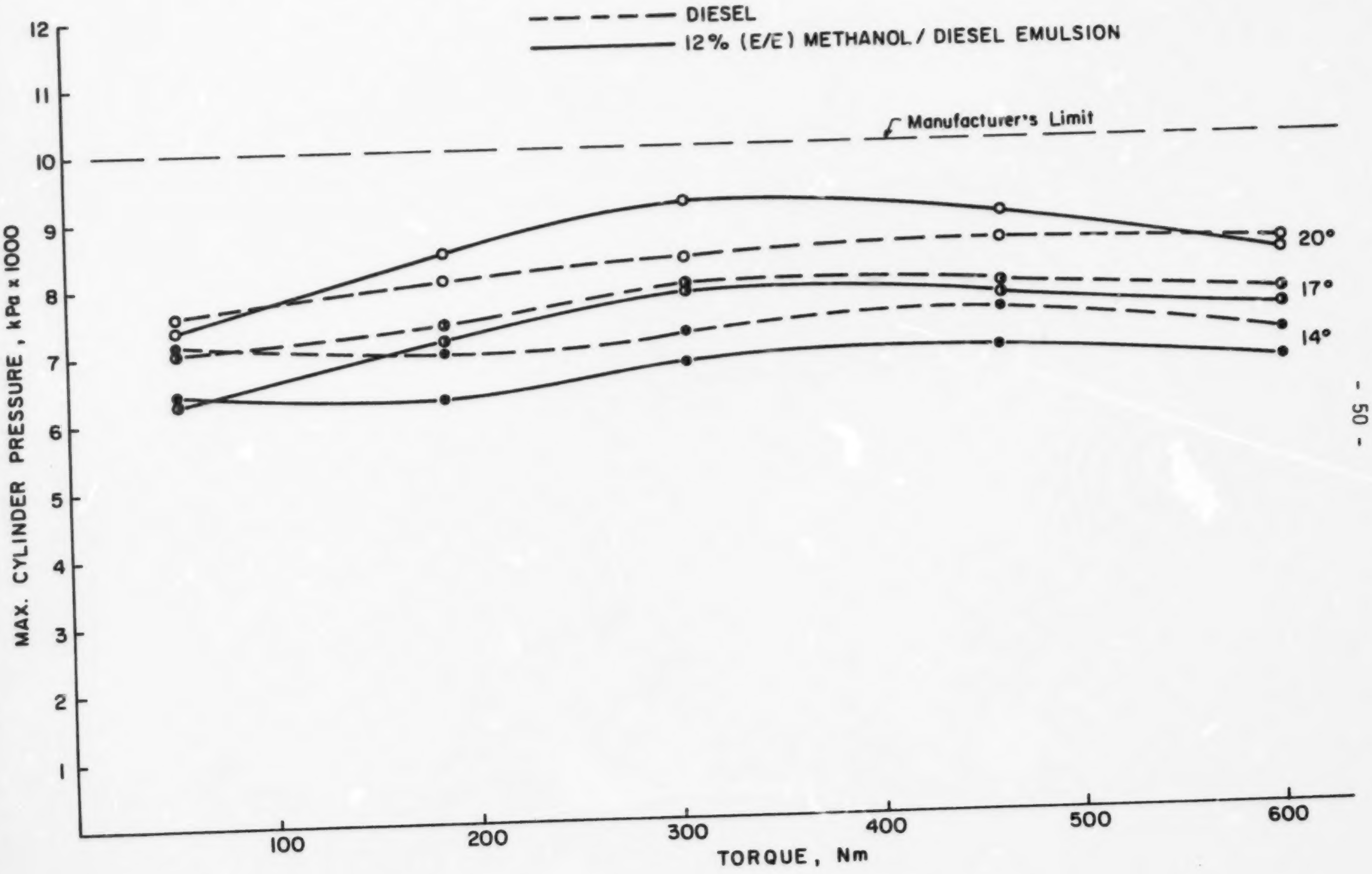

FIGURE 12: MAXIMUM CYLINDER PRESSURES FOR 1900 RPM CONDITIONS.

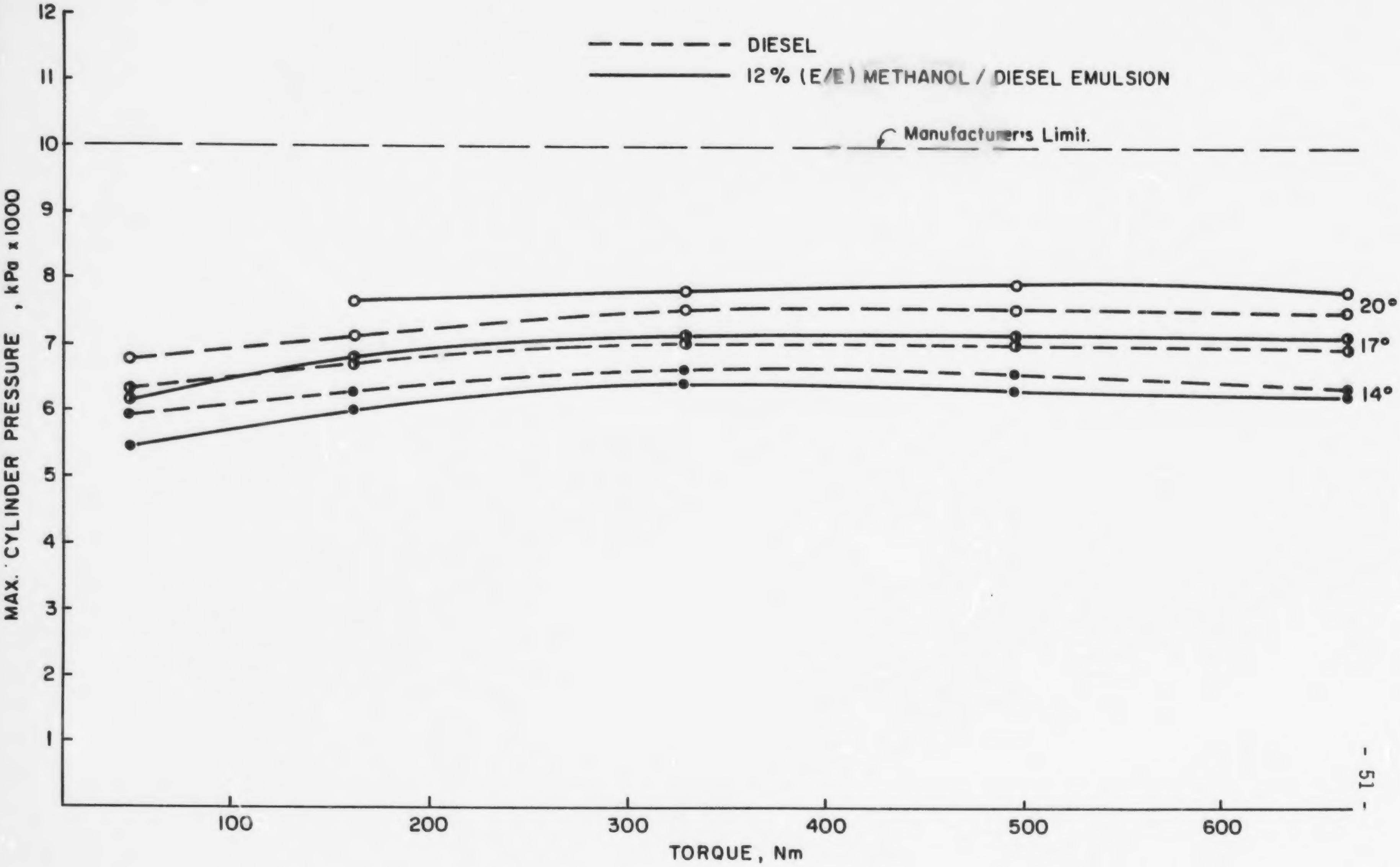

FIGURE 13: MAXIMUM CYLINDER PRESSURES FOR 1500 RPM CONDITIONS.

reducing cylinder pressure rates and/or ignition delay. It may be possible, however, to improve the combustion process by increasing the amount of energy to the glow plug at the expense of overall energy efficiency.

12.1.2 Advanced Static Injection Timings

Maximum cylinder pressure test results for 17° and 20° BTDC static timing setting, diesel fuel operation and 2300 RPM are presented in Tables 11 and, respectively 12. Advancing static injection timing by 3 CA° increases P_{max} by approximately 5% for diesel operation as shown in Figure 10. When static injection timing is advanced 6 CA° (20° BTDC) P_{max} is increased substantially by approximately 16%. Maximum cylinder pressures are generally the same for the load range (10% to 100% load) at a given static timing. Figures 10 through 13 give the P_{max} relationship versus load at the 17° and 20° injection timing settings. A decrease in P_{max} was observed for the 17° setting compared to 14° setting at 9% load condition. Slightly higher increases in P_{max} occur at 17° and 20° timing settings compared to the 14° setting on neat diesel engine operation.

Rates of cylinder pressure rise increase marginally when static injection timing is advanced to 17° BTDC with neat diesel at 2300 RPM. The ΔP_{max} increase is substantial and exceeds the 1,000 kPa/CA° recommended limit at 20° timing for the 2300 RPM speed condition.
Figure 11 illustrates the relationship of ΔP_{max} for timing settings of 17° and 20° BTDC at 2300 RPM. At 1900 RPM ΔP_{max} is increased by 30% at 17° timing and 70% at 20° timing compared to standard injection timing. Levels of ΔP_{max} at these test conditions (diesel fuel) are well below the manufacturers limit (Figure 14). For the 1500 RPM engine conditions ΔP_{max} is again well below the manufacturers limit as shown in Figure 15. Increases in ΔP_{max} are observed when torque is reduced for 1500 RPM condition at 17° and 20° timing and engine operation on diesel fuel.

Maximum cylinder pressures do not change significantly for engine operation on 12% (E/E) methanol/diesel emulsion at 2300 RPM speed conditions and 17° timing. When timing is advanced to 20° the effect of the emulsion is reduced P_{max} at torque conditions of 25% and above as shown in Figure 10. Marginal changes in P_{max} occur at 1900 RPM conditions for 17° and 20° timing and engine operation on methanol/diesel emulsion (see Figure 12). Similarly, minor changes in P_{max} are observed for the 1500 RPM condition at the two advanced timing settings (Figure 13).

Comparison of ΔP_{max} for engine operation on emulsion versus diesel at 17° and 20° timings and engine speeds of 2300, 1900 and 1500 RPM are given in Figures 11, 14 and 15, respectively. For 2300 RPM engine conditions ΔP_{max} is increased significantly during operation on emulsion at intermediate to high torque levels. Reductions in ΔP_{max} were observed for the low torque (10%) conditions at 17° and 20° timing. At 20° timing the ΔP_{max} levels are well in excess of the manufacturer's limit for the majority of engine load conditions at 2300 RPM. Maximum rates of pressure rise are increased significantly with emulsion at 17° timing and 1900 RPM conditions but are well below the 1,000 kPa/Ca° limit. Excursions in ΔP_{max} above the manufacturer's limit are evident at the 20° timing setting. Similarly, the manufacturer's limit is exceeded at some test points for the 1500 RPM speed conditions at 20° timing.

Tables 13 and 14 give the cylinder pressure test results for 12% (E/E) methanol/diesel emulsion at 17° and 20° timings, respectively. Application of auxiliary heat to the combustion chamber via glow plugs did not have a significant effect on combustion characteristics for emulsion at the advanced timing settings. Tables 15 and 16 give cylinder pressure results for these test conditions.

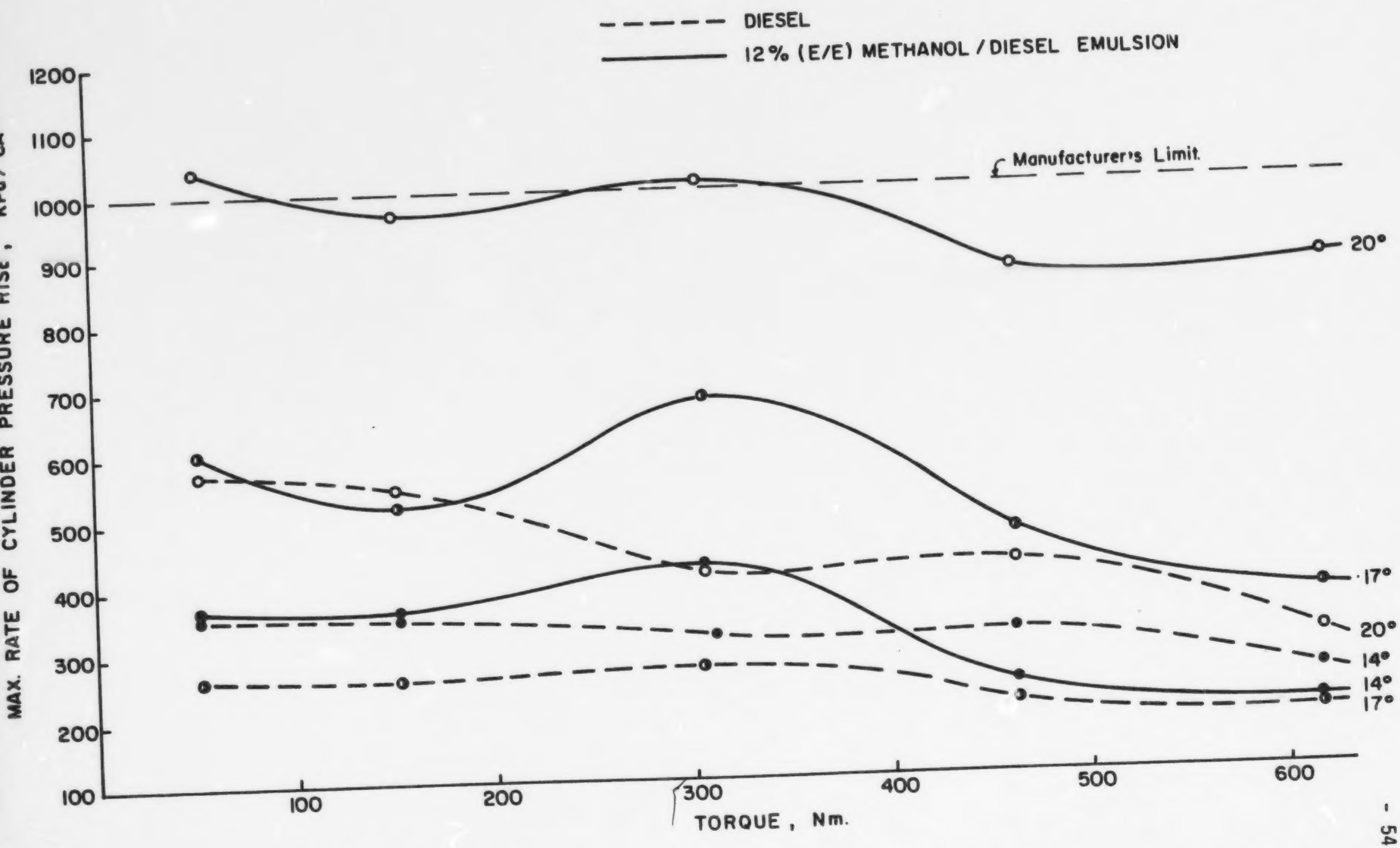

FIGURE 14: MAXIMUM RATE OF CYLINDER PRESSURE RISE FOR 1900 RPM CONDITIONS

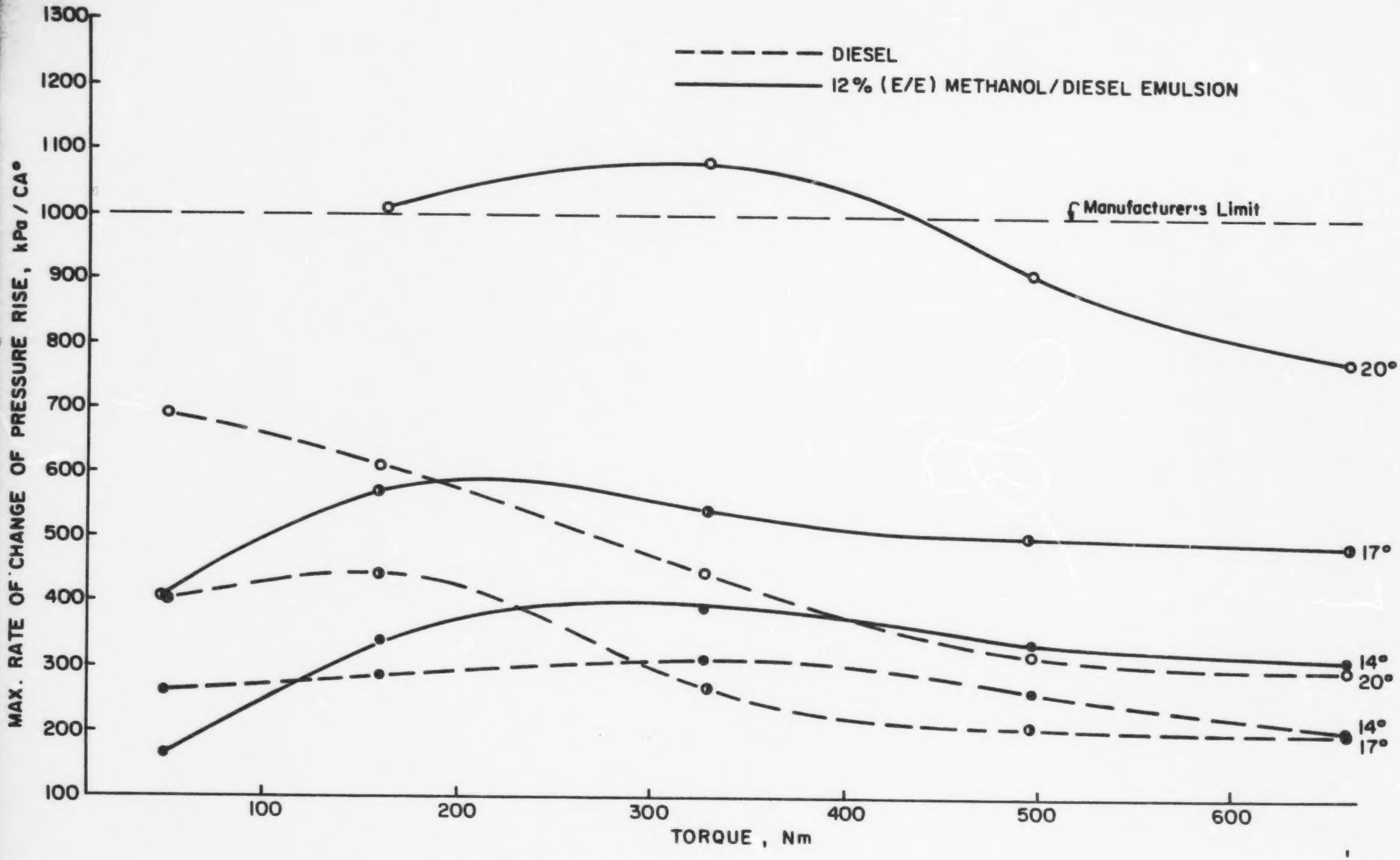

FIGURE 15: MAXIMUM RATE OF CYLINDER PRESSURE RISE FOR 1500 RPM CONDITIONS

12.1.3 Ignition Improved Emulsion

It was determined that 12% (E/E) methanol/diesel emulsion application to a compression ignition engine has a detrimental effect on cylinder pressures and engine fuel consumption characteristics (energy basis). Attempts to improve combustion and energy efficiency by advancing static injection timing and/or application of glow plug heat were both unsuccessful. It was decided to attempt to improve these conditions by addition of ignition improver to the emulsion via the methanol phase. This approach was selected on the basis of improving the cetane (ignition quality) number of the emulsion. An ignition improver (DII-3) supplied by Ethyl Corporation was selected for these studies.

Tables 17, 18 and 19 give the cylinder pressure and injection pressure test results for engine operation with 1.5, 3.0 and 4.5% (V/V) of ignition improver in 15% (E/E) methanol/diesel emulsion, repsectively . All tests were conducted at standard static injection timing (14^{o} BTDC). The addition of ignition improver to methanol/diesel emulsion lowers the peak cylinder pressures and significantly reduces ΔP_{max}. A general trend is observed where the higher the amount of ignition improver in emulsion the lower the P_{max} and ΔP_{max} at given engine conditions. Further, the location of P_{max} and Δ_{Pmax} is closer to piston top dead centre when ignition improver is added to the emulsion. The locations of P_{max} and ΔP_{max} for cetane improved emulsion are, delayed at light loads when compared to engine operation on diesel.

12.2 Fuel Injection Pressure Measurements

Results of the fuel injection pressure measurements are given in the Tables 8 through 17 presenting the combustion characteristics for given test conditions. In all cases the start of fuel pressure rise in the injection line is advanced by several crankangle degrees with methanol/diesel emulsion. Figure 16 illustrates a typical fuel injection pressure trace for emulsion and

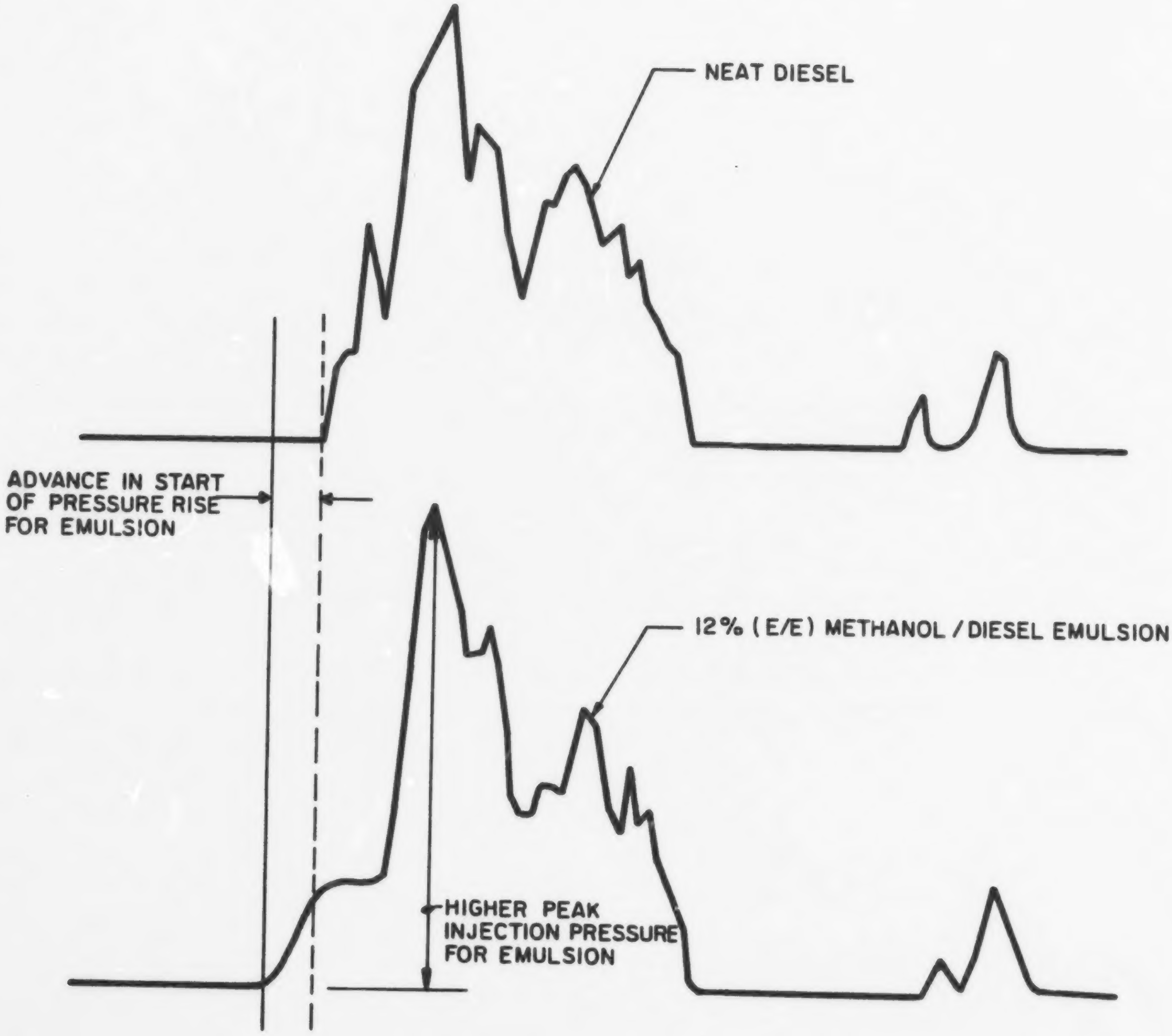

FIGURE 16: COMPARISON OF METHANOL / DIESEL EMULSION AND DIESEL FUEL INJECTION TRACES.

diesel. It is suspected that the advance in fuel pressure buildup is a function of the physical properties of the emulsion (i.e. viscosity, compressibility) as compared to standard diesel fuel.

A single phase fuel blend of 80% (V/V) diesel fuel, 10% (V/V) hexanol and 10% (V/V) methanol was prepared for engine tests. This fuel blend has a viscosity close to that of diesel fuel. Monitoring of fuel injection traces during engine operation on this blend revealed that the fuel pressure traces were close to that recorded for methanol/diesel emulsion. These results suggest that single or two phase methanol fuel blends have little effect on fuel pressure characteristics.

The column in the tables titled "P_{max} at Negative Slope" gives the injection line pressure values at which it is suspected that the injector needle lifts and allows fuel to enter the combustion chamber. There is a general trend for lower injection pressures for needle opening with emulsion as compared to neat diesel at given test conditions. The location for end of fuel injection tends to be delayed by 1 to 2 CA^{o} with methanol/diesel emulsion for most load/speed conditions. This delay is suspected to be a function of the increased quantity of fuel delivery per stroke with the methanol/diesel emulsion.

12.3 Fuel Energy Consumption Characteristics

Fuel consumption rates for engine operation on diesel fuel are presented in Tables 20, 21 and 22 for engine operation at 14^{o}, 17^{o} and 20^{o} static injection timing settings, respectively. Tables 23 through 27 give the fuel consumption rates on a mass and energy basis for 12% (E/E) methanol/diesel emulsion with and without application of glow plug heat.

Figure 17 graphically illustrates the fuel energy consumption rates for diesel fuel and 12% (E/E) methanol/diesel emulsion at 14^{o} timing and engine speed of 2300, 1900 and 1500 RPM. In all cases the fuel energy consumption is higher for emulsion than standard diesel fuel, particularly at intermediate

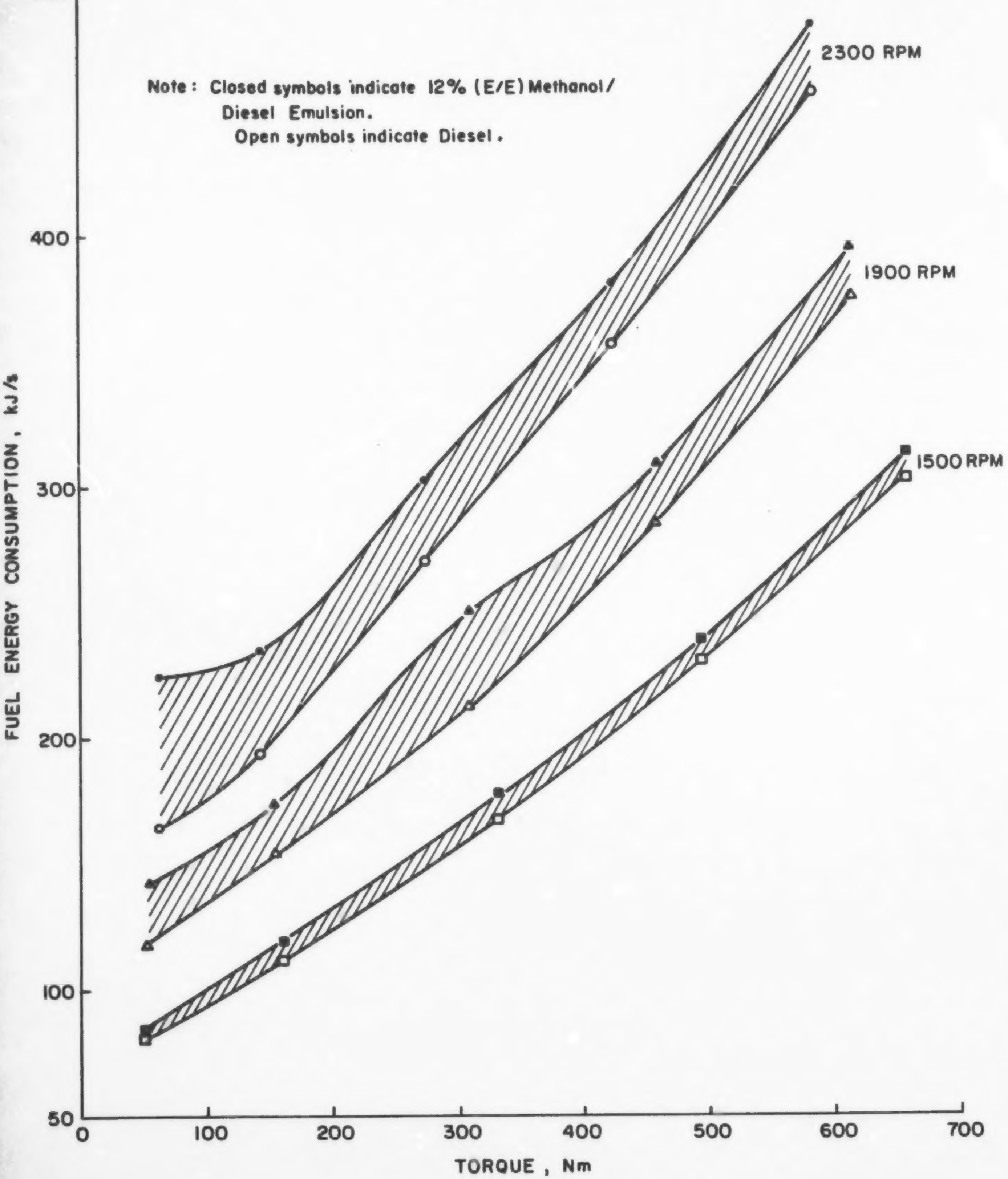

FIGURE 17: COMPARISON OF FUEL ENERGY CONSUMPTION RATES - DIESEL vs 12% (E/E) METHANOL/DIESEL EMULSION AT 14° TIMING

and light loads at 2300 RPM. This characteristic is due to the high engine speed and insufficient time for proper combustion with the emulsion. Ignition delay of 8 CA° at light loads with emulsion suggests that the fuel is burned late in the expansion cycle resulting in a reduction in engine efficiency.

Fuel energy consumption characteristics for standard diesel fuel, 12% (E/E) methanol/diesel emulsion and 15% (E/E) methanol/diesel emulsion at 17° static timing are shown in Figure 18. The 3 CA° advance in injection timing decreases the brake specific energy consumption (BSEC) for 1500 RPM conditions at 17° timing are similar to that observed at standard timing (14°). With 15% methanol/diesel emulsion the fuel energy consumption increased substantially (70% at 25% load) at 2300 RPM conditions. The percentage of methanol in the fuel greatly effects the efficiency of the engine.

Fuel energy consumption characteristics for the 20° static timing setting are nearly identical to those observed for the 17° setting. Figure 19 illustrates the fuel consumption data for 20° static timing setting.

Fuel energy consumption data for 15% (E/E) methanol/diesel emulsion with 1.5, 3.0 and 4.5 (V/V) ignition improver (Ethyl DII-3) is shown in Table 28. These data, along with non-ignition improved emulsion data, are presented in Figure 20. The addition of ignition improver is shown to have a beneficial effect on the efficiency of the engine. Generally the greater the amount of ignition improver the lower the BSEC. The higher fuel energy consumption rate measured for 2300 RPM/75° torque condition and 4.5% ignition improver is suspect. Emulsion concentration varied between 11% and 17% for these tests.

12.4 Emissions Test Results - Steady State Testing

The following subsections give the emissions test results for steady state engine operation with 15% (E/E) methanol/diesel emulsion and 2.4% (V/V) ignition improver in the emulsion. Static injection timing was set to 14° BTDC for all tests and test data are compared to emissions measured for engine operation on standard diesel fuel.

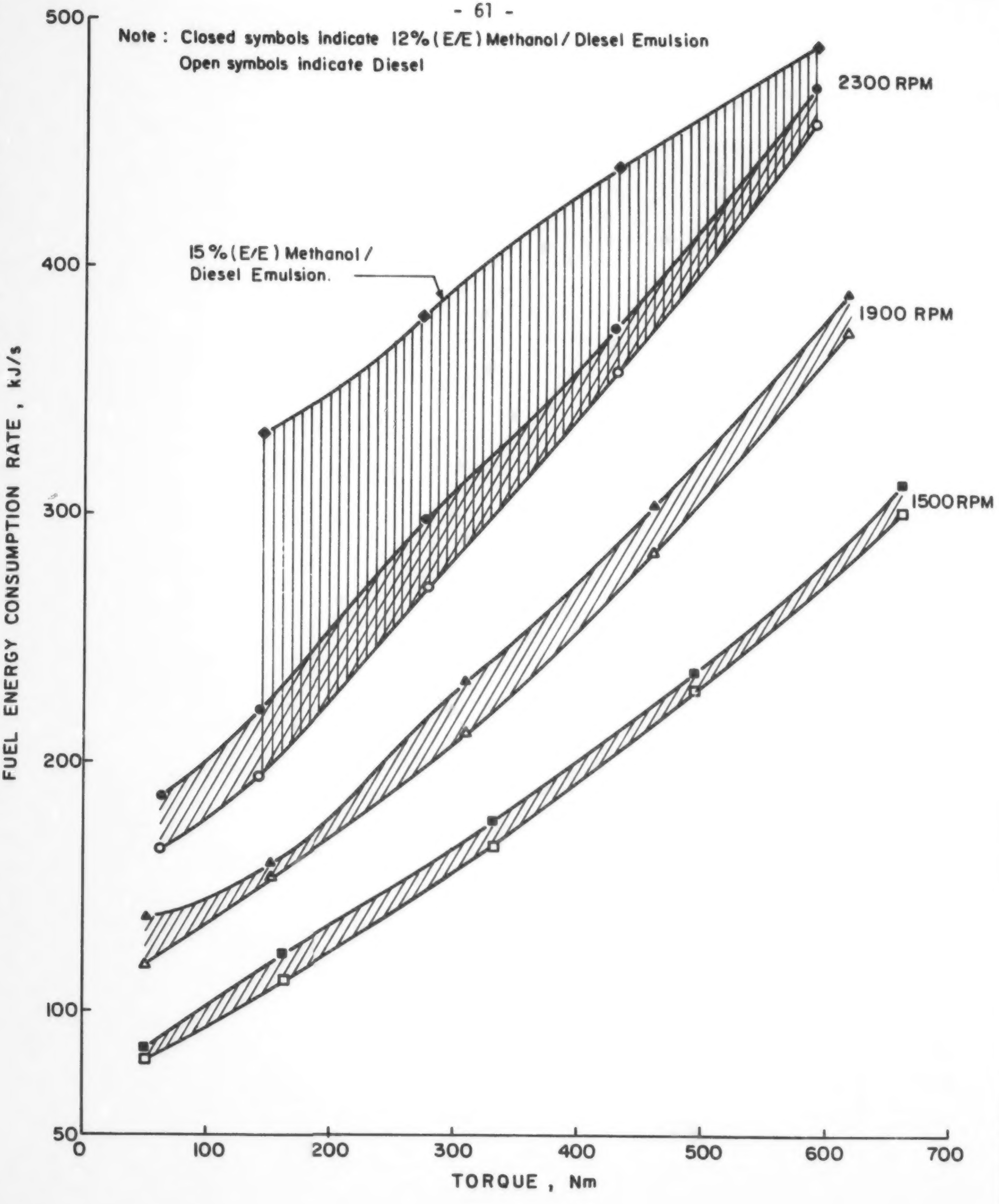

FIGURE 18: COMPARISON OF FUEL ENERGY CONSUMPTION RATES DIESEL AT 14° TIMING vs 12% (E/E) & 15% (E/E) METHANOL / DIESEL EMULSION AT 17° TIMING

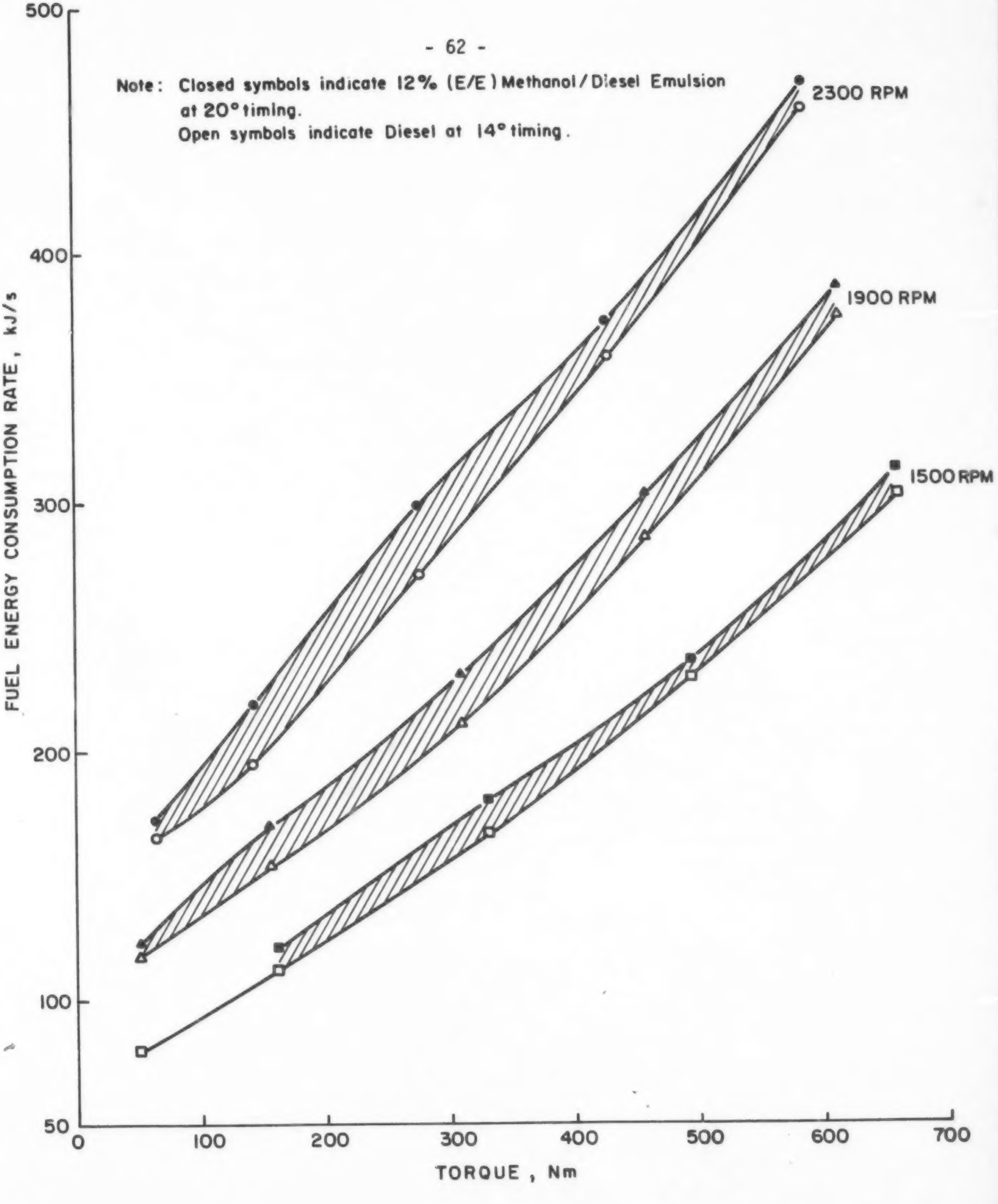

FIGURE 19: COMPARISON OF FUEL ENERGY CONSUMPTION RATES DIESEL AT 14° TIMING vs 12% (E/E) METHANOL/DIESEL EMULSION AT 20° TIMING

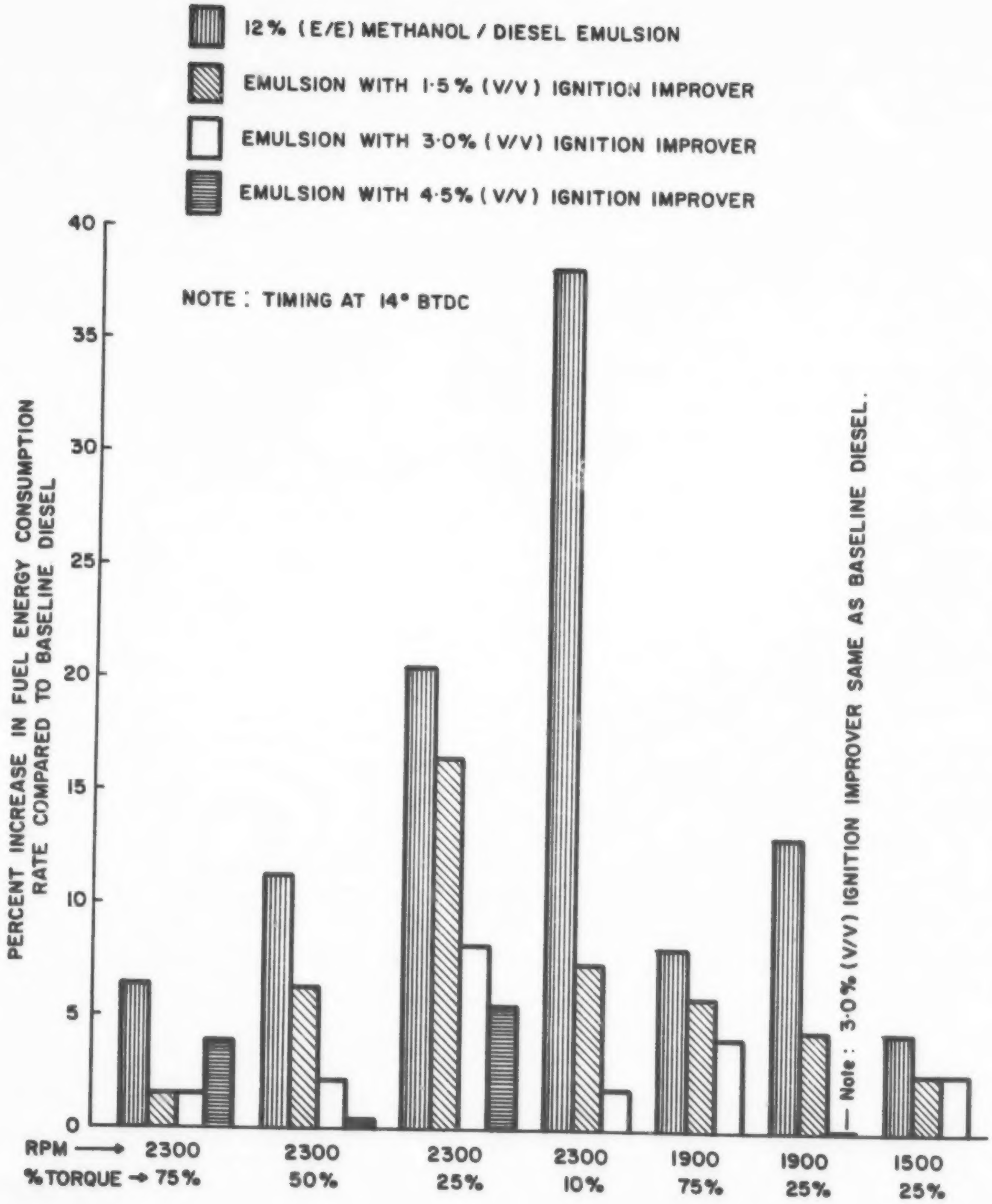

FIGURE 20 : EFFECT OF EMULSION WITH AND WITHOUT IGNITION IMPROVER ON ENERGY CONSUMPTION.

12.4.1 Particulate Emissions

Engine exhaust particulate concentrations for diesel fuel and methanol/diesel emulsion are presented in Table 29. Methanol/diesel emulsion had the effect of lowering the insoluble particulate concentrations for all speed/load conditions tested. Soluble particulate concentrations were reduced with methanol/diesel emulsion for three (3) of the twelve (12) speed/load conditions and increased for the other nine (9) test conditions. Total particulate (soluble and insoluble) concentrations increased with emulsion at 25% load condition for engine speeds of 2300, 1900 and 1500 RPM. An increase in total particulate concentration was also observed for the 1900 RPM/50% load condition. The effect of methanol/diesel emulsion on insoluble and soluble particulate emissions is presented in Table 30 and illustrated in Figure 21. Percent changes in total particulate emissions with emulsion are illustrated in Figure 22 and also presented in Table 30.

Mass emissions (grams per hour) of insoluble, soluble and total particulate for diesel fuel and methanol/diesel emulsion are given in Table 31. Brake specific mass emissions (grams per kilowatt hour are presented in Table 32.

12.4.2 Gaseous Emissions

Exhaust concentrations of CO, THC, NO, NO_2 and No_x for engine fuelling with standard diesel fuel and methanol/diesel emulsion are given in Table 33. Mass emissions of these pollutants are given in Table 34. and Table 35 presents the percentage change in these emissions relative to engine operation on diesel fuel. Figures 23, 24 and 25 graphically illustrate these changes in emissions.

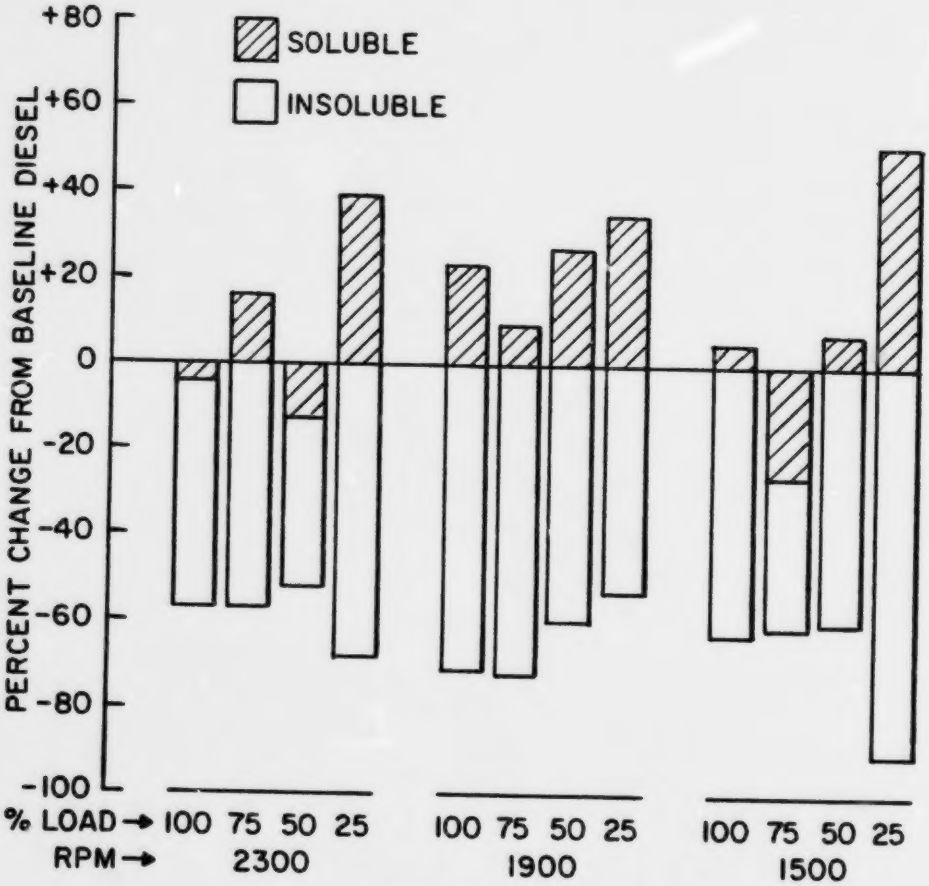

Figure 21: EFFECT OF 15% (E/E) METHANOL/DIESEL EMULSION ON INSOLUBLE AND SOLUBLE PARTICULATE EMISSIONS.

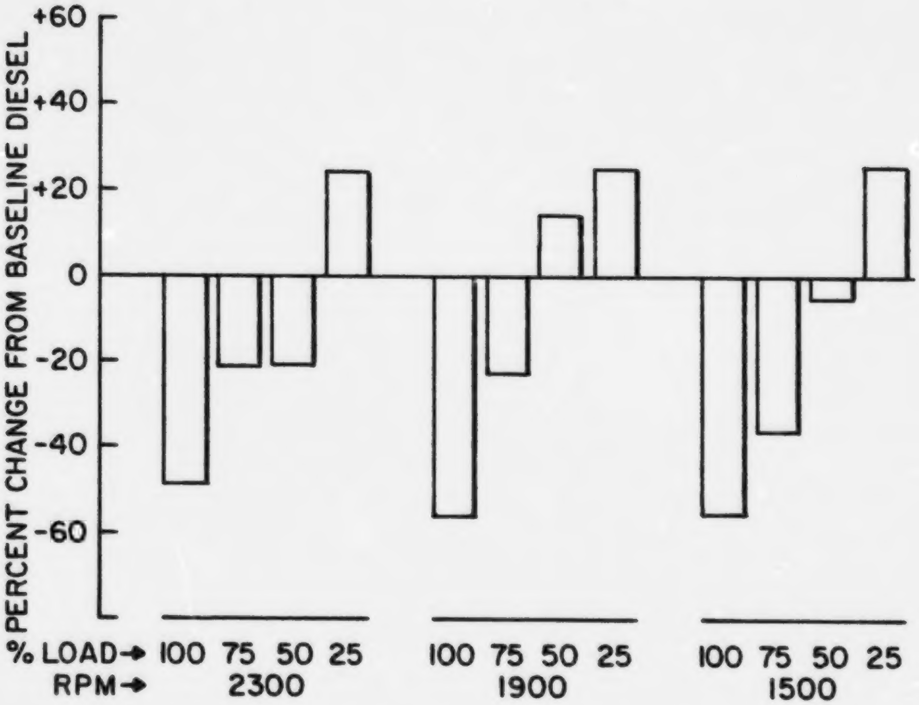

Figure 22: EFFECT OF 15% (E/E) METHANOL/DIESEL EMULSION ON TOTAL PARTICULATE EMISSIONS.

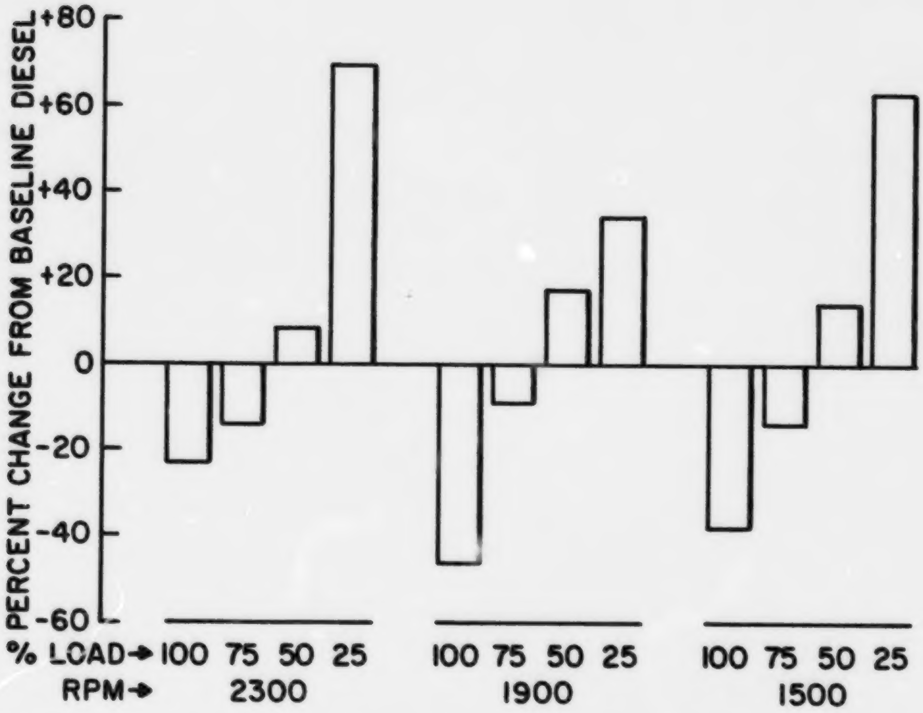

Figure 23: EFFECT OF 15% (E/E) METHANOL/DIESEL EMULSION ON CARBON MONOXIDE EMISSIONS.

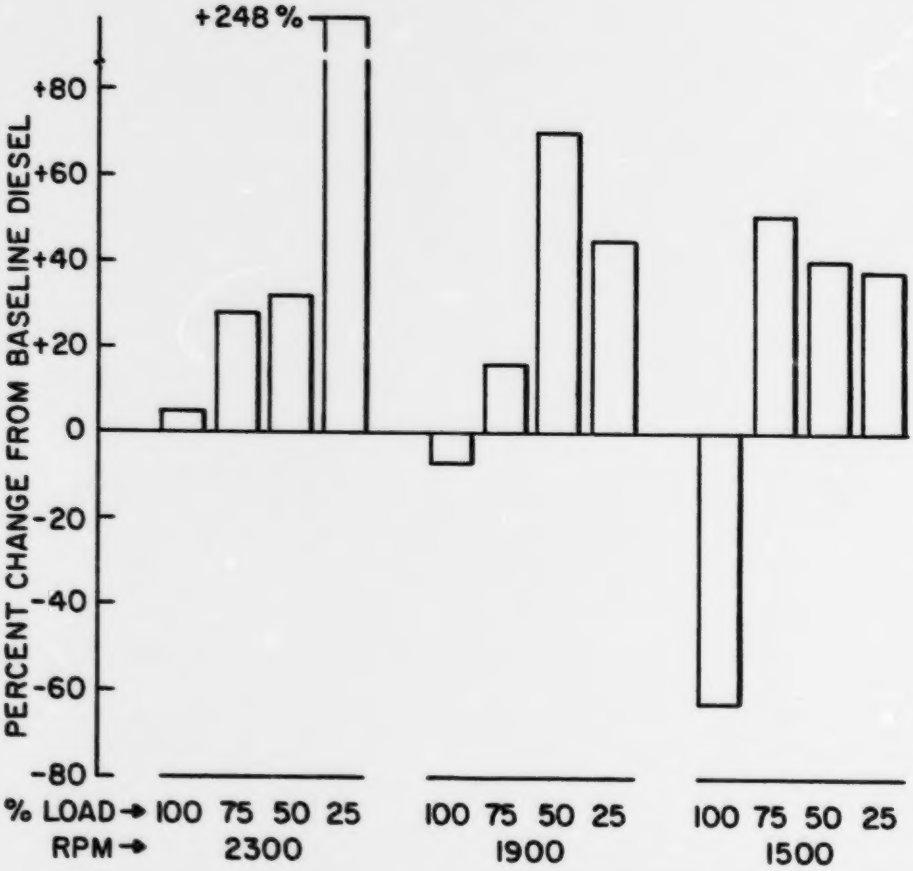

Figure 24: EFFECT OF 15%(E/E) METHANOL/DIESEL EMULSION ON TOTAL HYDROCARBON EMISSIONS.

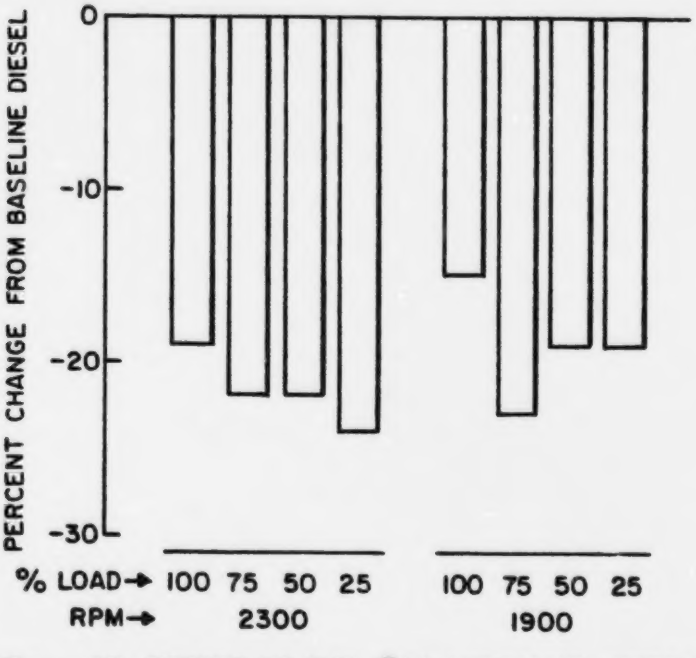

Figure 25: EFFECT OF 15% (E/E) METHANOL/DIESEL EMULSION ON NITROGEN OXIDES EMISSIONS .

Carbon monoxide emissions are reduced with methanol/diesel emulsion at the 100% and 75% load condition for each of the three engine speeds. The percent reduction was highest (23% to 45%) for the 100% load conditions. Increases in CO emissions are found at the 50% and 25% load conditions with the greater increases (34% to 69%) at the 25% loads. These trends in CO emissions tend to follow those observed for total particulate emissions with methanol/diesel emulsion.

Total hydrocarbons (THC) emissions data (expressed as equivalent methane) should be reviewed carefully since the flame ionization detector does not respond well to oxygenated hydrocarbons present in the exhaust with methanol/diesel emulsion. Reductions in THC emissions are evident at the 100% load conditions for engine speeds of 1900 and 1500 RPM. At all other test conditions THC emissions were increased substantially. A maximum increase of 248% is found for the 2300 RPM/25% load condition.

Reductions in emissions of total NO_x are obtained with methanol/diesel emulsion. These reductions vary between 15% and 24% when compared to emissions measured with engine operation on diesel fuel. Increases in NO_2 emissions are evident with emulsion and it is suspected that this is attributable to the partial decomposition of octyl nitrate in the ignition improver. The reductions in nitric oxide emissions are primarily due to the reduced peak combustion temperature and ignition delay associated with methanol/diesel emulsion.

12.4.3 Aldehyde Emissions

Aldehyde concentration test results are presented in Tables 36 and 37 for engine operation with standard diesel fuel and methanol/diesel emulsion, respectively. Total aldehyde concentrations vary between 5.7 ppm and 18.2 ppm, depending on the speed/load condition, for fuelling with diesel fuel. Formaldehyde accounts for approximately 66 to 69% of the total aldehydes for these test conditions. Problems were encountered during

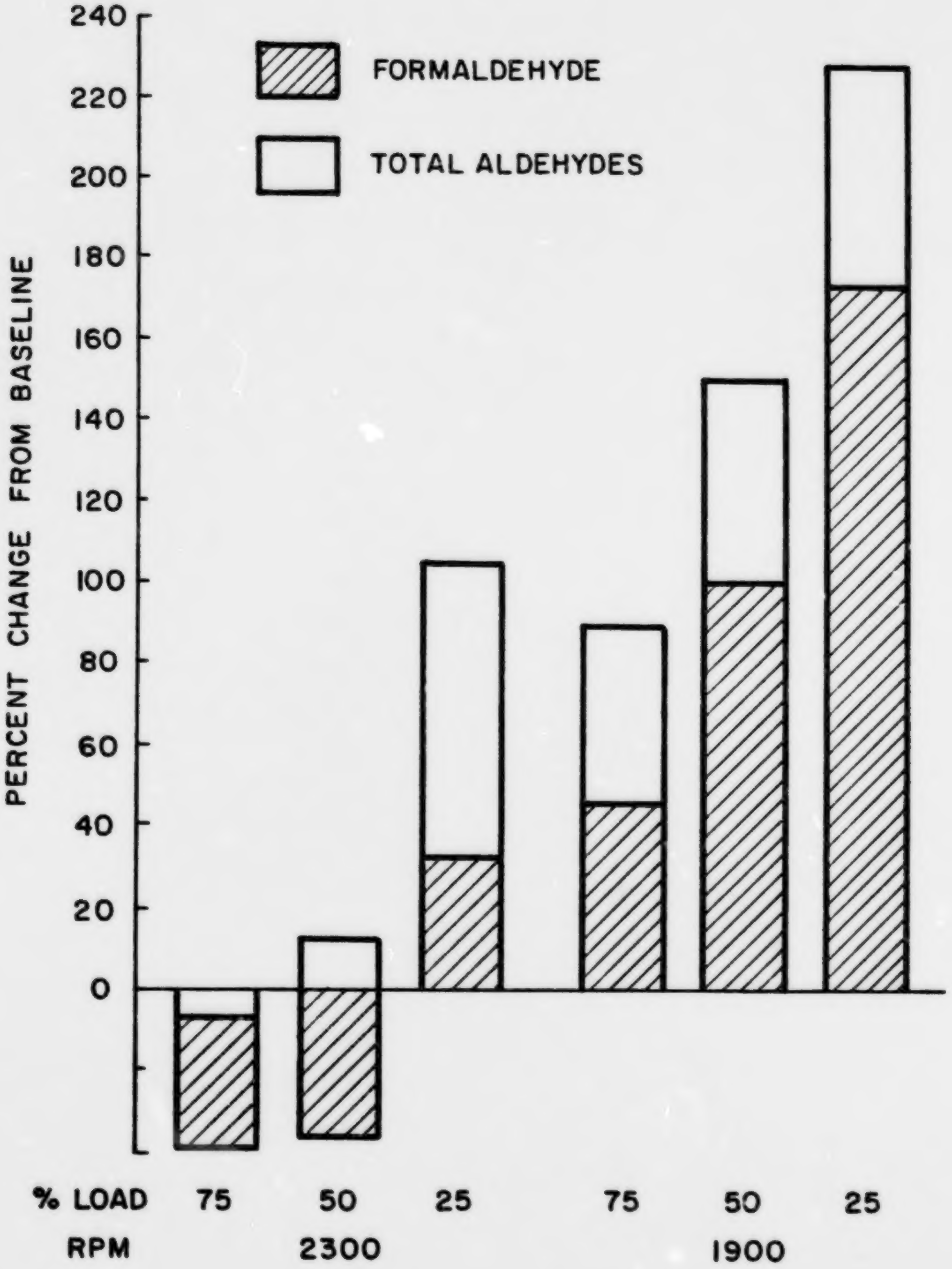

FIGURE 26 EFFECT OF 15% (E/E) METHANOL / DIESEL EMULSION ON TOTAL ALDEHYDE AND FORMALDEHYDE EMISSIONS

analysis for the determination of acetone concentrations. Suspected contamination of the samples prevented accurate analysis and, therefore, results are excluded.

Increases in total aldehyde concentrations were found for all test conditions with application of methanol/diesel emulsions except 2300 RPM/15% Load. Increases of 13 to 228% are observed with emulsion. Formaldehyde accounts for a lower percentage of total aldehydes than was found for the standard diesel fuel tests. This trend indicates that the higher aldehydes (i.e. acetaldehyde, crotonaldehyde etc.) contribute to the overall aldehyde emissions associated with the emulsion.

Figure 26 shows the changes in formaldehyde and total aldehydes emissions with application of emulsion.

12.5 Emissions Test Results - Transient MTU-LHD Cycle

The following subsections present the particulate, gaseous, aldehyde and unburned methanol emissions test results for simulated engine operation over a LHD mines duty cycle. In all cases, the MTU-LHD cycle was used to characterize the exhaust emissions for engine operation on ignition improved 15% (E/E) methanol/diesel emulsion and diesel fuel (except unburned aldehydes). Comparison of test results between steady state and transient tests is difficult since the methanol percentage for the two conditions is different. However, where possible, comparisons were made between the two test conditions. Appendix C gives the engine parameters listing for engine operation on methanol/diesel emulsion over the MTU-LHD cycle.

Table 38 gives the average engine conditions during the MTU-LHD cycle for engine fuelling with diesel and the emulsion.

12.5.1 Particulate Emissions

Results of the particulate emissions tests for engine operation on diesel and cetane improved 15% (E/E) methanol/diesel emulsion over the MTU-LHD cycle are presented in Table 39. Soluble particulate emissions for diesel and emulsion averaged 52.8 mg/m^3 and 47.9% mg/m^3, respectively, resulting in a 9.3% reduction due to methanol/diesel emulsion. A substantial (61%) reduction in insoluble particulate was found for emulsion (9.13 mg/m^3) as compared to engine operation on diesel fuel (23.6 mg/m^3). Total particulate emissions (soluble and insoluble) were reduced by 25% with the methanol/diesel emulsion.

12.5.2 Gaseous Emissions

Average concentrations of CO, CO_2, THC, NO, NO_x and NO_2 for engine fuelling with diesel and cetane improved 15% (E/E) methanol/diesel emulsion over the MTU-LHD cycle are presented in Table 40 Table 41 gives the corresponding average mass emissions rates of these gaseous compounds for the two test conditions. The increased CO_2 for engine operation on emulsion is the reverse trend of that observed for steady state testing. Carbon monoxide emissions were increased by 11% with the emulsion. This increase appears to coincide with CO emission trends observed for steady state testing.

Average total hydrocarbon emissions (expressed as methane) were virtually the same for the two fuels for engine operation over the cycle. A considerable reduction in nitric oxide emissions (23%) was found with the engine operating on the cetane improved emulsion over the MTU-LHD. This characteristic may be due to lower peak combustion temperature inherent with the burning of methanol fuel. Emissions of nitrogen dioxide were increased substantially from 7.56 g/h to 43 g/h with the cetane improved emulsion. This increase in NO_2 appears to be attributable to the presence of octyl nitrate in the fuel. Total oxides of nitrogen (NO_x) was reduced by 17% over the MTU-LHD cycle with methanol/diesel emulsion.

12.5.3 Aldehyde Emissions

Individual aldehyde concentrations measured for engine operation on diesel fuel and cetane improved 15% (E/E) methanol/diesel emulsion over the MTU-LHD cycle are presented in Table 42. Appendix D gives the analytical data for the carbonyl analysis. Cycle formaldehyde emissions were reduced by 45% with application of methanol/diesel emulsion This trend is opposite to that observed during steady state testing at the lower loads and could reflect higher loads during cycle. The cycle reduction results from the improved combustion of the cetane improved fuel. Further, the steady state results are somewhat inconsistent. Formaldehyde accounts for 57% of the total aldehydes with diesel fuel operation and 41% with methanol/diesel emulsion.

Emissions of acetaldehyde were reduced by 25% with the emulsion fuel whereas acetone emissions increased by 17%. Methyl ethyl ketone and isobutraldehyde concentrations increased from 262 $\mu g/m^3$ (diesel) to 1070 $\mu g/m^3$ with the emulsion.

Total aldehyde emissions were reduced by 23% over the MTU-LHD cycle with application of 15% methanol/diesel emulsion (with cetane improver). The ratio of formaldehyde to total aldehydes follows similar trends for cycle testing and steady state testing.

12.5.4 Unburned Methanol Emissions

The results of tests performed to determine emissions of unburned methanol during engine operation with methanol/diesel emulsion over the MTU-LHD cycle are presented in Table 43. Tests were not conducted for engine operation on diesel fuel. Average concentration of methanol in the exhaust was 38.8 $\mu g/m^3$ resulting in a mass emission rate of 25.0 grams per hour.

13. ENGINE INSPECTION

Subsequent to the completion of test runs for combustion and emissions analysis with methanol/diesel emulsion the number one cylinder unit was partially disassembled and inspected. Crankcase oil analysis was performed for purposes of analyzing the oil characteristics. The following subsections describe the results of each of these activities. Approximately 300 hours of engine operation was recorded during the test program. It is estimated that one third of this time was with engine fuelling with methanol/diesel emulsion.

13.1 Combustion Chamber

Figure 27 shows combustion deck of the number one cylinder head with the exhaust valve on the right side of the photograph. Some scaling of the combustion deck is observed on the lower portion of the combustion deck (opposite prechamber discharge port). It is suspected that this scaling may be attributable to materials attack by the partially decomposed products of methanol combustion or methanol itself. Similar scaling was observed on the piston top (see Figure 28) in the same area of the combustion chamber.

Figure 29 shows the cylinder liner of number one cylinder with the piston near bottom dead centre. A good cylinder cross-hatch was still in the liner with no apparent signs of scuffing or abnormal wear.

Unfortunately, there was insufficient operating time on the engine with methanol/diesel emulsion to allow for a proper wear assessment. A long term durability test (at least 500 hours) is necessary to properly analyze the effects of methanol/diesel emulsion on the engine components.

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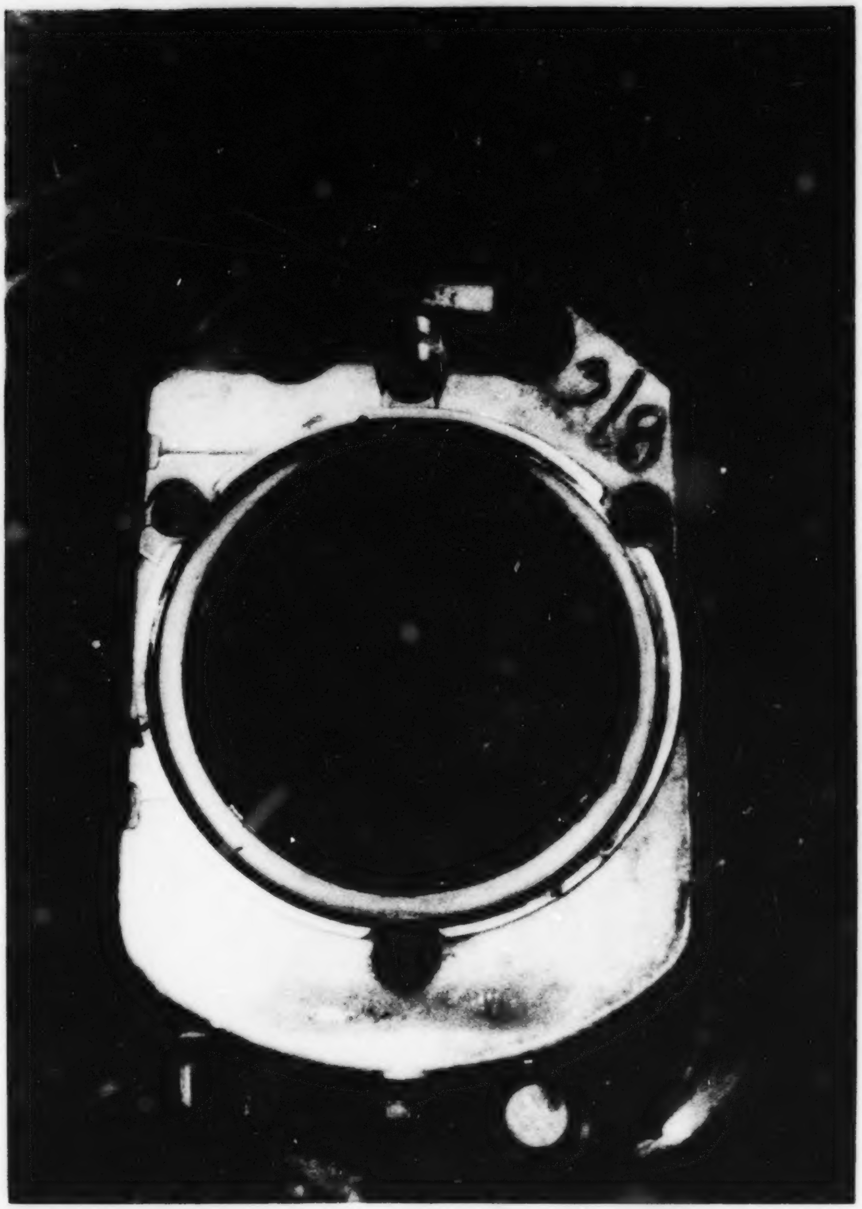

FIGURE 27 View of cylinder head and valves.

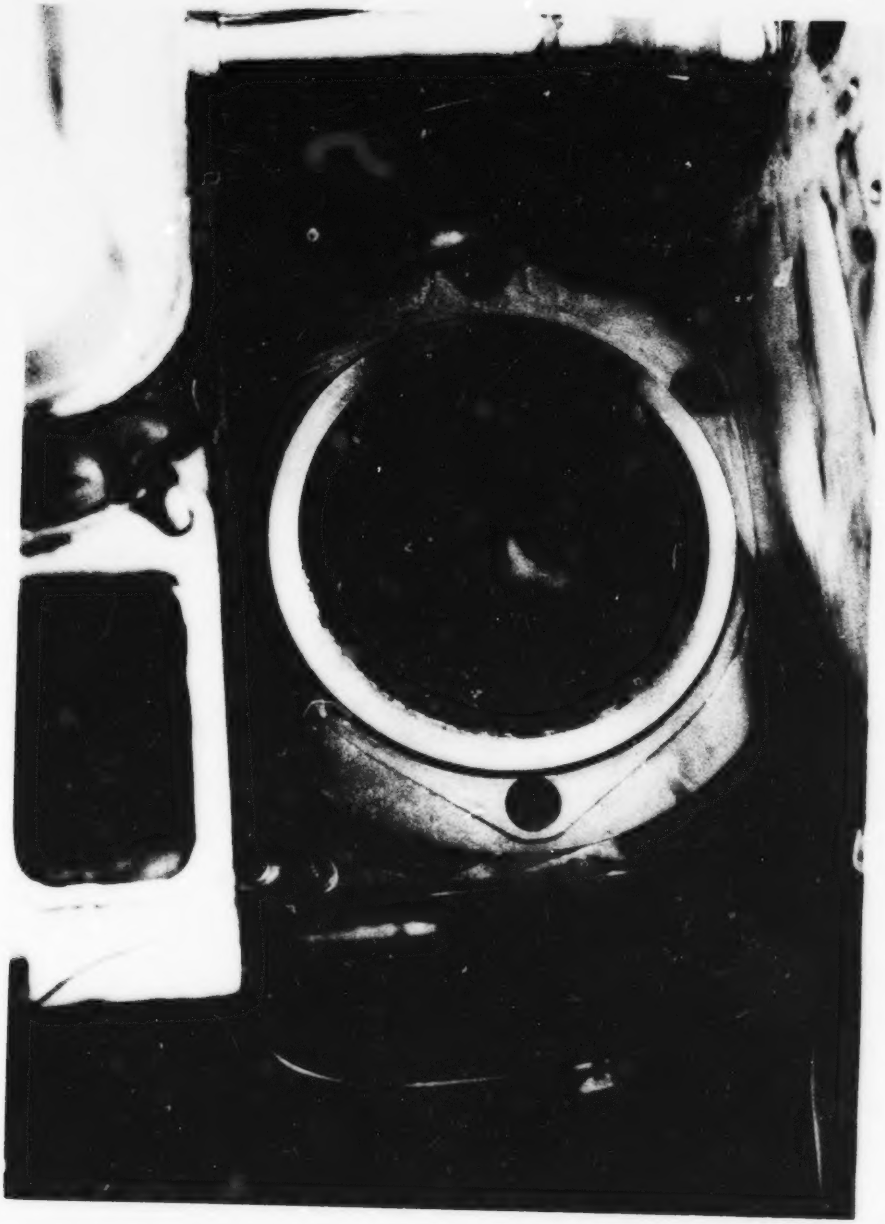

FIGURE 28 Top of piston. Note aluminum scaling on piston top (opposite fuel injection).

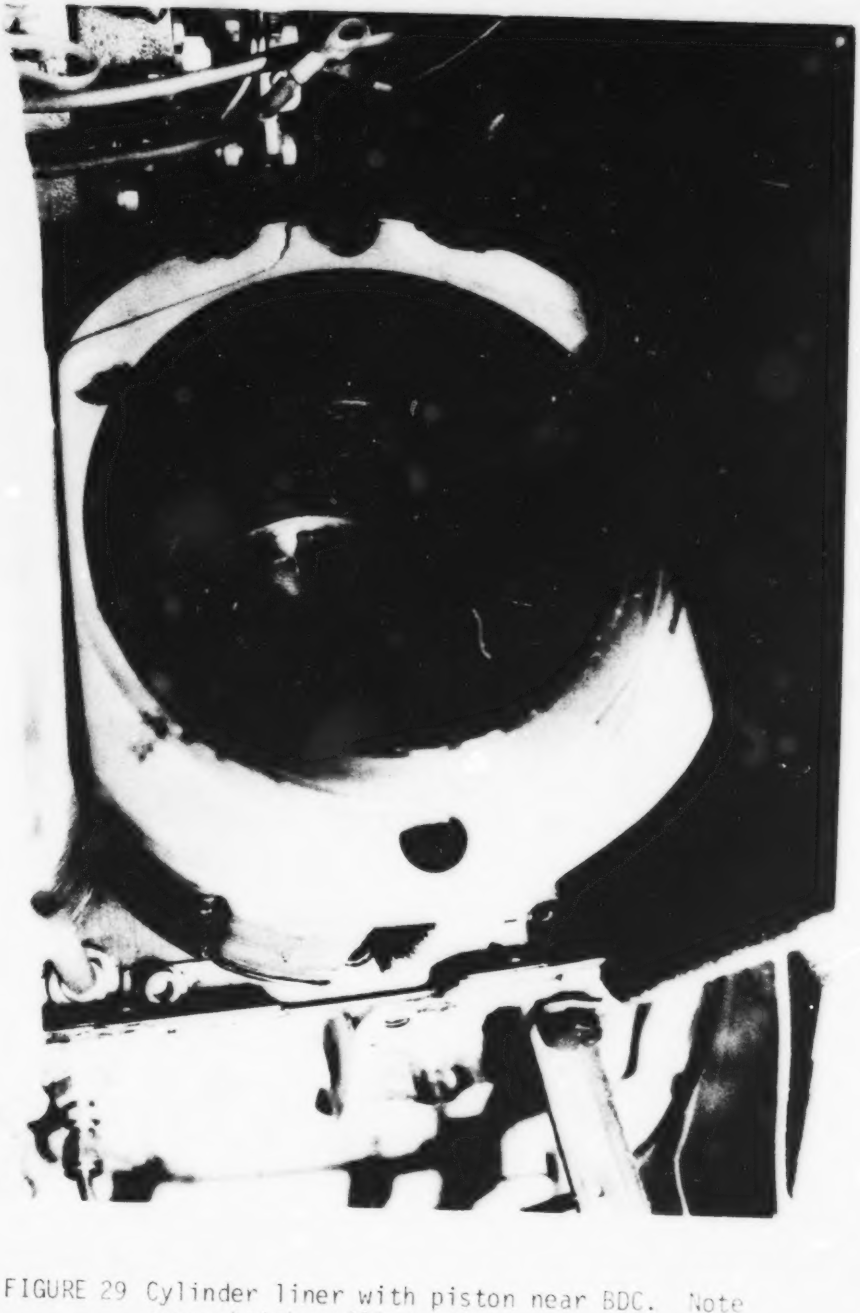

FIGURE 29 Cylinder liner with piston near BDC. Note cross-hatch still in liner.

13.2 Crankcase Oil Wear Analysis

Following 100 hours of engine operation the crankcase oil was drained and samples sent to a laboratory for analysis. Approximately 80% of these hours were accumulated with 15% methanol/diesel emulsion. Table 44 shows the analyzed levels for metals and physical properties of the test oil. Maximum acceptable levels are also given in this table. Relatively high levels (53 ppm) of copper were found in the oil which suggests possible bearing wear. The analytical laboratory recommended that additional hours be accumulated on the engine with subsequent oil analysis to determine if the high copper level is of concern. The high copper level in the oil may be a function of the engine "breaking in" since only 300 hours of engine operation was recorded.

In all other cases the oil analysis showed that no abnormal engine wear was taking place. Zinc is added to the oil as an additive.

14. DISCUSSION

14.1 General

Application of unstabilized 12% (E/E) methanol/diesel emulsion, without assisting the ignition properties of the fuel, results in a decrease in engine efficiency. The reduction in efficiency is primarily a result of combustion ignition delay. Ignition delay is caused by the low ignition quality of the emulsion and the following factors.

- The high latent heat of vapourization of methanol cools the compressed air charge as fuel is injected and thus reduces the propensity for the fuel to autoignite at a given piston position (compression temperature).

- The reduced heating value of methanol requires that a greater volume of fuel be injected with emulsion to produce a given power output. This results in a longer injection duration where more fuel is burned in the later part of the expansion cycle.

Attempts to improve combustion by advancing the injection timing result in higher peak cylinder pressures and rates of cylinder pressure rise. When combustion takes place in advance of piston top dead centre the rates of pressure rise and peak cylinder pressures increase. These characteristics result in increased mechanical stresses on some engine components such as piston pins, connecting rods, bearings and crankshaft.

Increasing the percentage of methanol in the emulsion from 12% (E/E) to 15% (E/E) without ignition improver results in a substantial loss of engine efficiency and significantly impaired exhaust emission quality can be expected. The results indicate that the maximum utilization of methanol in emulsions is limited to concentration of less than 12 percent on an energy basis.

Combustion and fuel efficiency (engine efficiency) can be improved with the application of ignition improver to the unstabilized emulsion. With the addition of 2.4% (V/V) octyl nitrate ignition improver to the emulsion allows engine operation with 15% (E/E) methanol/diesel emulsion with a slight increase in fuel energy consumption rate. The ignition improver enhances the autoignition properties of the emulsion and thereby decreases the ignition delay. Improved exhaust emissions quality results with the exception of NO_2, where, it is suspected, partial decomposition of nitrate in the ignition improver takes place.

Regulation of the methanol to diesel ratio according to engine speed and load is impossible to achieve with the modified Bosch fuel system. The rapid fuel delivery transients of a typical LHD vehicle and large fuel system volume do not allow for precise metering of the methanol. For these reasons, it was necessary to design and calibrate the emulsion fuel system to deliver a fixed ratio of methanol/diesel emulsion to the combustion chamber.

Fumigation may resolve the ratio modulation problem, however, poor energy efficiency is still expected. Further fumigation requires a considerable amount of heat to vapourize the fuel prior to entering the combustion chamber. The complexity of a methanol fumigation system may be undesirable in underground mining operations.

14.2 Exhaust Quality Index

A potential benefit for the application of unstabilized methanol/diesel emulsion in a compression ignition engine is improved exhaust emissions. The sections in this report detailing exhaust emission test results show a wide variation in emissions reduction with emulsion. These variations result from the different operating conditions of the engine (i.e. speed/load) and the fact that the emissions are markedly different over a transient cycle than steady state operation. Further, results show that, for a given test condition, a reduction in one or more pollutant concentrations may be at the expense of increasing a separate pollutant concentration.

A formula has been proposed which addresses the overall impact of some diesel exhaust pollutants, simultaneously present, one the mine air quality. The formula, developed by I.W. French and Associates, takes into account specific threshold limit values (TLV's) for specific gaseous pollutants and respirable combustible dust (RCD). Although this formula, designated the air quality index (AQI), is primarily intended for mine air quality assessment, it has been used to evaluate the effectiveness of diesel emission control strategies. Thus, an exhaust quality index (EQI) has been derived. The exhaust quality index is expressed as follows:

where TLV_{CO} = 50 ppm
TLV_{NO} = 25 ppm
TLV_{RCD} = 2 mg/m
TLV_{SO} = 3 ppm
TLV_{NO} = 3 ppm

This formula attempts to reflect the concern of the synergistic health effects of RCD, or diesel exhaust particulate, with SO_2 and NO_2 as indicated by the respective weighting factors of 1.5 and 1.2.

The EQI formula was used to assess the impact of unstabilized methanol/diesel (ignition improved 15% (E/E) on the emissions from a conventional mines engine. Table 45 gives the input data and results of calculations using the EQI. Sulphur dioxide (SO_2) concentrations are based on a fuel sulphur content of 0.2% (W/W) and it is assumed that all fuel sulphur is released from the exhaust as SO_2. The SO_2 values for methanol/diesel emulsion are based on diesel values corrected for the displaced volume of diesel fuel. Total particulate test results were used to define the RCD values.

Methanol/diesel emulsion decreases the EQI value by about 17% for the MTU-LHD transient cycle test conditions. Considerable reductions in the EQI are evident at the 100% load conditions at 2300 and 1900 RPM. Reductions in EQI values are still observed at the 75% loads for the same engine speeds although the reductions are not as great. At the 50% load condition for 1900 RPM an increase (15.1%) in the EQI occurs whereas a reduction (15.2%) is found at the 2300 RPM condition. Considerable increases in EQI values were found for the 25% load condition for engine speeds of 2300 and 1900 RPM.

These data indicate that there is a negative emissions impact at light engine loads when using unstabilized methanol/diesel emulsion. It is suspected that this trend would be more pronounced at engine idle conditions. Unfortunately, there are no test data to confirm this suspicion. The MTU-LHD cycle may not be representative of an LHD mines cycle since the cycle does not include any engine idle period. For this reason, it is suspected that the exhaust emissions from an emulsion fuelled engine would be greater over a typical mines shift than its diesel counterpart. This negative effect may be circumvented by ensuring that the emulsion is not used during light load or engine idle condition. Provision for such control adds to the complexity and cost of the fuel system.

The emissions benefit of utilizing methanol/diesel emulsion in an LHD mining machine may be realized in a dead heading of an underground mine. Dead headings are typically poorly ventilated and are areas where the LHD machine is operating at a high load factor. These conditions suggest that methanol/diesel emulsion would improve the mine air quality in specific areas of the underground mine.

The EQI does not take into account pollutants such as aldehydes, methyl nitrate, unburned methanol and others. Test results show that methanol/diesel emulsion increases aldehydes for steady state conditions, particularly at light loads, and decreases aldehydes for the MTU-LHD cycle. Again the MTU-LHD cycle is not fully representative of an LHD cycle for a typical mine shift. Emissions of aldehydes would, therefore, be expected to be higher over a shift, than indicated by the MTU/LHD test results. These increased aldehyde emissions may be controlled using exhaust aftertreatment device(s) such as catalytic converters.

Results of a previous CANMET program (DSS Serial No. 0SQ76-00162) showed total particulate reductions of 79% and 62% for rated speed and torque conditions, respectively, with methanol/diesel emulsion (without ignition improver). The study was conducted with 10% (E/E) methanol/diesel emulsion in a Deutz F6L-714 indirect injection diesel engine (25^{o} BTDC timing). These reductions are greater than that observed for similar engine conditions under this contract (48% and 55%). Also, the previous test program showed increases in NO_x of 17% with emulsion for rated speed and rated torque conditions. NO_x emissions in this study were, however, reduced by 43% and 53% at the same engine conditions.

It appears that the discrepancy in emissions test results between these two engines operating on methanol/diesel emulsion is related to engine combustion sensitivity. The older 714 series Deutz engine has a relatively early injection timing compared to the newer 413 series engine. This should allow the 714 engine to burn more efficiently, the poorer quality fuel early in the combustion process. Increased NO_x results with the 714 engine tend to support this theory. It appears, therefore, that the 714 series is a more tolerant engine to poorer quality fuels.

15. CONCLUSIONS

Unstabilized methanol/diesel emulsion can be used to fuel an indirect injection, compression ignition mining engine. There are, however, factors that influence the viability of this approach in terms of economic trade-offs between fuel cost and the potential for reduced mine ventilation costs as a result of improved emissions.

There appears to be a general agreement that the cost of diesel fuel will increase and quality of diesel fuel will continue to deteriorate in the future. Although the future price for fuel grade methanol will also increase, however, the price ratio relative to diesel fuel is uncertain. It can also be expected that the quality of methanol will be relatively consistent. These factors may tend to be favourable for using methanol as a fuel in the future.

This study has shown that ignition improver must be added to unstabilized emulsion in order to achieve reasonable engine efficiency and exhaust emissions quality. Discussions with suppliers have revealed that the cost for a typical ignition improver is in the order of $3.89 Cdn per litre if ordered in bulk quantities. Typical prices for diesel fuel and methanol are $0.273 Cdn and $0.15 Cdn per litre respectively. The fuel cost for 15% methanol/diesel emulsion with ignition improver, is therefore, approximately

18% higher than conventional diesel fuel. This increase is based on a diesel fuel cost that is tax exempt and is a typical current price for a mine operation. The cost increase is higher when taking into account the reduced fuel efficiency associated with methanol/diesel emulsion.

The increased fuel costs incurred in modifying an engine to operate on methanol/diesel emulsion must be taken into account and compared with the potential savings in mine ventilation costs.

Recent developments in modifying heavy duty engines to operate on 100% methanol (M100) have shown that engine performance and exhaust emissions can be improved significantly over a diesel fuelled counterpart. These M100 engines do not require the use of fuel additives to ensure satisfactory combustion, efficiency and emissions but there may be other problems in using these engines underground. In at least three cases these engines should fit into existing LHD mining machines with minor modifications to the machine.

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HCV:DT:sw:sd

APPENDIX A

Tables - Test Results

ORF

TABLE I

PROPERTIES OF LIQUID FUELS

	Methanol	Gasoline	Diesel	Year 1990 Diesel
Chemical formula	CH_3OH	C_8H_{17}	$C_{12}H_{26}$	
		Mixtures of Hydrocarbons		
Molecular weight of liquid fuel	32	113	170	
Specific gravity g/cc	.796	.702	.876	.8779
Heating value Low kJ/kg High kJ/kg	 19,955 22,700	 39,900 43,700	 42,447 44,749	 42,260
Specific heat at constant pressure C_p				
of liquid fuel $\frac{kJ}{kg^oK}$ 60-80°F	2.533	2.093	1.884	
of fuel vapour $\frac{kJ}{kg^oK}$ at 60°F	1.716	1.675 approx.	1.675 approx.	
of chemically correct mixture vapour and air 60°F $\frac{kJ}{kg^oK}$	1.026	1.047 approx.	1.047 approx.	
Stoichiometric air requirement $\frac{kg\ air}{kg\ fuel}$	6.5	14.9	15.0	
Ratio of specific heats K chemically correct mixture	1.38	1.35 approx.	1.35 approx.	
fuel vapour	1.11 estimated	1.05 approx.	1.35 approx.	
Molecular weight of stoichiometric mixture of fuel and air.	29.4	30.3	30.5	

TABLE I (cont'd).

PROPERTIES OF LIQUID FUELS (continued)

	Methanol	Gasoline	Diesel	Year 1990 Diesel
Octane # Research Motor	112 91	91-97 82-87		
Cetane #	3	8-14	40 min.	35
Flash Point °C	11.1	-43	55	60
Viscosity CSt. at 20°C approx.	.9	.6	4	
Distillation Temp °C 90% point		180°C	288°C	354
Latent heat of Vapourization J/g	1,119	293-344	544-795	
Boiling Temp. °C	65°	70-90	150-360	166-388
Self ignition temp. °C	385 478	300-450°C	316	
Ignition limits air fuel ratio kg air/kg fuel	2.15-12.8	6.0-22.0	.6-6.5 *	
Mixture heating value kJ/kg air	3,073	2,980	-	
Reid Vapour Pressure psi	4.6	7-15	-	
Sulphur % wt.	0	.01	0.1-0.5 typically 0.25	
Carbon residue %			0.91	
Pour Point °C			-43- -15	
Flammability % volume	6.6-36	1.4-7.6		
at temp. limits °C	7-41	-22 @ low CR		
Freezing point °C	-98	-57°C		
H_2O solubility H_2O in ppm		88		

* Vol. % gas in air

TABLE I (cont'd).

PROPERTIES OF LIQUID FUELS (Continued)

	Methanol	Gasoline	Diesel	Year 1990 Diesel
Surface Tension dyne/cm	22.6			
Specific resistivity	$.14 \times 10^6$	2×10^6		
Combustion reaction Equation	$CH_3OH + 1.5\ O_2 + 5.66\ N_2 = CO_2 + 2H_2O + 5.66\ N_z$	$C_nH_{2n} + 1.5\ O_2 + 5.66_nN_2 = n\ CO_2 + nH_2O + 5.66_nN_2$		
By weight				
% carbon	37.5	85.88	86.38	
% hydrogen	12.6	12.15	12.66	
% oxygen	49.9			

TABLE 2

Load-Haul-Dump Cycle Analysis at Falconbridge's Lockerby Mine

			TIME IN SECONDS				
Cycle No.	Run up Stope	Muck	Back out Stope	Haul	Dump	Back from Dump	Total
4	28	125	30	29	15	29	256
5	25	64	27	28	15	31	190
6	25	60	26	30	14	30	185
7	25	90	29	30	-	-	-
8	25	85	20	30	10	28	198
9	27	70	25	33	11	30	196
10	30	70	32	31	14	31	208
11	29	120	32	30	18	29	258
12	34	60	23	31	11	34	193
13	30	26	32	31	15	29	163
14	28	54	28	30	12	29	181
15	28	114	28	31	11	37	249
Average	28	77	28	30	13	31	207
% Time in Segments	13.5%	37.2%	13.5%	14.5%	6.3%	15.0%	

TABLE 3

Duty Cycle Analysis

Cycle No.	Run up Stope		Muck		Back out of Stope		Haul		Dump		Backup from Dump	
	Rack	Speed	Rack	Speed	Rack	Speed	Rack	Speed	Rack	Speed	Rack	Speed
4	7.7	1950	7.7	1760	6.3	2000	7.7	1975	5.9	2000	6.5	1975
5	7.0	2000	7.9	1733	5.0	2025	7.5	1990	5.7	2000	6.6	1950
6	7.5	2000	7.8	1836	6.3	2000	7.6	1980	6.3	2025	6.2	1980
7	7.4	1980	7.3	1827	6.5	2025	7.4	2000	-	-	-	-
8	7.4	2000	7.5	1678	6.1	2050	7.0	1980	6.8	2025	6.0	1950
9	8.9	1970	6.0	1722	6.7	2025	7.4	1990	7.4	2025	6.2	1980
Average	7.5	1983	7.4	1759	6.2	2021	7.4	1986	6.4	2015	6.3	1967

Rack - mm

Speed - rpm

TABLE 4

Actual LHD Cycle Analysis at Falconbridge's Lockerby Mine

Cycle	Time Sec.	Speed rpm	Rack mm	Torque lb.ft	Maximum Available Torque lb.ft	% of Maximum Torque At Speed
Run up Stope	28	1983	7.5	317	420	76
Mucking	77	1759	7.4	307	480	64
Run out of Stope	28	2021	6.2	150	200	75
Haul to Ore Pass	30	1986	7.4	307	400	77
Dump	13	2015	6.4	160	220	73
Backup	31	1967	6.3	210	437	48
					Average	69

Deutz F8L 413 F/W Diesel Engine with a PE8A RSV Governor

TABLE 5

Simulated LHD Cycle Analysis
For a Deutz F8L 413 F/W
Diesel Engine with a PE8A RSV Governor

Cycle	Time Sec.	Speed rpm	Rack mm	Torque lb.ft	Maximum Available Torque lb.ft	% of Maximum Torque At Speed
Run up Stope	29	1908	7.68	334	473	71
Mucking	118	1765	9.08	453	476	95
Run out of Stope	30	1952	6.40	207	450	46
Haul to Ore Pass	26	1906	7.35	297	477	62
Dump	21	1910	7.50	311	473	66
Backup	30	1798	7.46	303	480	63
					Average	67

Notes: Mucking cycle data of 3 sec was eliminated due to no torque values for low rpm.

% of maximum torque is the average of all the maximum torque %'s. When a value was over 100% just 100% was recorded, therefore the % will not correspond to the % when calculated using the average torques.

TABLE 6

Simulated LHD Cycle for Deutz F8L 413 FW

	Time Sec	Speed rpm	Rack mm	Torque lb.ft	Maximum Available Torque lb.ft	% of Maximum Torque
Run up Stope	1	1940	7.22	290	457	63
	2	1500	9.43	490	500	98
	3	1330	10.01	517	527	98
	4	1620	9.43	490	480	100
	5	1800	9.26	470	480	98
	6	1900	9.23	467	480	97
	7	1950	9.09	456	450	100
	8	1970	7.73	339	433	78
	9	1975	6.78	260	423	61
	10	1980	6.58	244	417	59
	11	1975	6.88	267	423	63
	12	1965	7.73	337	437	77
	13	1970	6.88	267	433	62
	14	1980	6.81	260	417	62
	15	1980	6.54	237	417	57
	16	1970	7.29	300	433	69
	17	1960	7.97	366	440	83
	18	1965	8.17	384	437	88
	19	1980	7.15	287	417	69
	20	1980	6.54	237	417	57
	21	1970	7.15	287	433	66
	22	1965	7.83	346	437	79
	23	1975	7.83	346	423	82
	24	1980	6.88	267	417	64
	25	1980	6.54	237	417	57
	26	1970	7.29	300	433	69
	27	1960	8.07	373	440	85
	28	1975	7.73	337	423	80
	29	1900	6.54	237	480	49
Mucking	30	1590	9.19	470	483	97
	31	1810	9.26	470	480	98
	32	1865	9.26	470	480	98
	33	1490	9.60	506	503	100
	34	1080	10.11	524	540	97
	35	950	6.41	183	-	-
	36	860	5.50	97	-	-
	37	820	5.88	133	-	-
	38	1230	9.09	440	540	81
	39	1450	9.87	513	507	100
	40	1600	9.53	500	480	100
	41	1750	9.26	470	480	98
	42	1720	9.26	470	480	98
	43	1770	9.26	470	480	98
	44	1740	9.26	470	480	98
	45	1800	9.26	470	480	98
	46	1900	9.23	467	480	97
	47	1820	9.23	467	480	97
	48	1720	9.23	467	480	97
	49	1800	9.23	467	480	97
	50	1880	9.23	467	480	97

TABLE 6 (cont'd)

	Time Sec	Speed rpm	Rack mm	Torque lb.ft	Maximum Available Torque lb.ft	% of Maximum Torque
Mucking	51	1450	9.77	463	507	91
	52	1750	9.26	456	480	95
	53	1810	9.26	463	480	96
	54	1880	9.23	463	480	96
	55	1920	9.19	463	467	99
	56	1930	9.09	456	463	98
	57	1820	9.19	463	480	96
	58	1730	9.19	463	480	96
	59	1820	9.19	463	480	96
	60	1900	9.19	463	480	96
	61	1930	8.92	447	463	97
	62	1880	9.16	460	480	96
	63	1900	9.16	460	480	96
	64	1850	9.16	460	480	96
	65	1750	9.16	460	480	96
	66	1620	9.26	477	480	99
	67	1400	9.87	506	510	99
	68	1460	9.77	503	503	100
	69	1550	9.60	503	490	100
	70	1580	9.43	493	487	100
	71	1600	9.33	483	480	100
	72	1750	9.26	467	480	97
	73	1880	9.26	467	480	97
	74	1930	9.16	460	463	99
	75	1880	9.16	460	480	96
	76	1830	9.19	463	480	96
	77	1800	9.19	463	480	96
	78	1820	9.19	463	480	96
	79	1850	9.19	463	480	96
	80	1880	9.19	463	480	96
	81	1890	9.19	463	480	96
	82	1900	9.19	463	480	96
	83	1890	9.19	463	480	96
	84	1830	9.19	463	480	96
	85	1850	9.09	454	480	95
	86	1460	9.19	470	503	93
	87	1500	9.77	520	500	100
	88	1640	9.26	477	480	99
	89	1770	9.26	467	480	97
	90	1850	9.26	467	480	97
	91	1910	9.19	463	473	98
	92	1830	9.19	463	480	96
	93	1720	9.19	463	480	96
	94	1600	9.33	483	480	100
	95	1640	9.33	463	480	100
	96	1580	9.33	483	487	99
	97	1630	9.33	483	480	100
	98	1800	9.26	467	480	97
	99	1880	9.26	467	480	97
	100	1940	9.23	467	457	100

TABLE 6 (cont'd)

	Time Sec	Speed rpm	Rack mm	Torque lb.ft	Maximum Available Torque lb.ft	% of Maximum Torque
Mucking	101	1910	9.16	460	473	97
	102	1950	9.16	460	450	100
	103	1960	7.90	353	440	80
	104	1500	7.22	290	500	58
	105	1560	9.43	490	490	100
	106	1680	9.33	479	480	100
	107	1670	9.26	477	480	99
	108	1730	9.26	477	480	99
	109	1830	9.26	467	480	97
	110	1920	9.19	463	467	99
	111	1960	9.19	463	440	100
	112	1830	9.09	456	480	95
	113	1640	9.26	474	480	99
	114	1590	9.26	474	483	98
	115	1520	9.43	490	497	99
	116	1430	9.77	494	507	97
	117	1330	9.24	454	527	86
	118	1340	10.08	524	523	100
	119	1510	9.94	533	500	100
	120	1700	9.40	490	480	100
	121	1830	9.26	467	480	97
	122	1910	9.26	467	473	99
	123	1940	9.23	467	457	100
	124	1960	7.90	354	440	80
	125	1960	6.88	267	440	61
	126	1920	8.75	433	467	93
	127	1910	9.16	460	473	97
	128	1910	9.16	460	473	97
	129	1920	9.16	460	467	99
	130	1820	9.09	454	480	95
	131	1620	9.26	477	480	99
	132	1320	9.94	513	527	97
	133	1700	9.33	483	480	100
	134	1810	9.26	467	480	97
	135	1900	9.19	463	480	96
	136	1950	9.19	463	450	100
	137	1980	7.39	310	417	74
	138	1970	6.20	183	433	42
	139	1800	9.09	456	480	95
	140	1740	9.19	463	480	96
	141	1870	9.19	463	480	96
	142	1940	9.19	463	457	100
	143	1970	8.58	417	433	96
	144	1990	7.22	290	387	75
	145	2000	6.03	187	237	79
	146	1980	5.69	150	417	36
	147	1950	6.88	267	450	59
	148	1940	8.75	433	457	95
	149	1940	9.13	460	457	100
	150	1950	9.58	483	450	100

TABLE 6 (cont'd)

	Time Sec	Speed rpm	Rack mm	Torque lb.ft	Maximum Available Torque lb.ft	% of Maximum Torque
Run out of Stope	151	1910	8.99	450	473	95
	152	1840	9.13	460	480	96
	153	1650	9.19	470	480	98
	154	1400	9.67	497	510	97
	155	1650	9.33	483	480	100
	156	1830	9.26	467	480	97
	157	1940	9.23	467	457	100
	158	1970	8.07	373	433	86
	159	2000	6.88	267	237	100
	160	2020	5.52	124	143	87
	161	2030	5.08	77	100	77
	162	2020	5.08	77	143	54
	163	2000	5.35	106	237	45
	164	2010	5.69	147	183	80
	165	2020	5.52	127	143	89
	166	2030	5.18	90	100	90
	167	2020	5.05	70	143	49
	168	2000	5.35	106	237	45
	169	2010	5.69	147	183	80
	170	2020	5.46	117	143	82
	171	2030	5.18	124	100	100
	172	2020	5.12	83	143	58
	173	2000	5.35	106	237	45
	174	2010	5.66	144	183	79
	175	2020	5.35	106	143	74
	176	2030	5.08	77	100	77
	177	2020	5.18	90	143	63
	178	2000	5.52	127	237	54
	179	2020	5.69	147	143	100
	180	2030	5.18	90	100	90
Haul to Ore Pass	181	2020	5.18	90	143	63
	182	1980	5.52	127	417	30
	183	1650	9.09	463	480	96
	184	1200	10.28	537	540	99
	185	1530	9.94	474	493	96
	186	1770	9.30	474	480	99
	187	1840	9.26	467	480	97
	188	1920	9.26	467	467	100
	189	1960	8.99	450	440	102
	190	1980	7.56	323	417	77
	191	1990	6.71	250	387	65
	192	1990	6.03	170	387	44
	193	1980	6.20	194	417	47
	194	1970	7.49	316	433	73
	195	1980	7.29	300	417	72
	196	1990	6.54	237	387	61
	197	1990	6.03	174	387	45
	198	1980	5.96	163	417	39
	199	1970	7.22	283	433	65
	200	1980	7.39	307	417	74

TABLE 6 (cont'd)

	Time Sec	Speed rpm	Rack mm	Torque lb.ft	Maximum Available Torque lb.ft	% of Maximum Torque
Haul to Ore Pass	201	1990	6.54	240	387	62
	202	1980	6.03	170	417	41
	203	1970	6.54	237	433	55
	204	1970	7.29	300	433	69
	205	1980	7.05	280	417	67
	206	1990	6.37	220	387	57
Dump	207	1980	6.20	190	417	46
	208	1970	6.88	267	433	62
	209	1940	7.39	307	457	67
	210	1880	9.16	460	480	96
	211	1830	9.16	460	480	96
	212	1830	9.16	460	480	96
	213	1860	9.16	460	480	96
	214	1870	9.16	460	480	96
	215	1450	9.16	483	503	96
	216	1640	9.77	517	480	100
	217	1850	9.26	467	480	97
	218	1930	9.26	467	463	100
	219	1980	8.92	447	417	100
	220	2000	6.88	267	237	100
	221	2020	5.86	174	143	100
	222	2020	5.18	86	143	60
	223	2010	5.12	83	183	45
	224	2000	5.35	106	237	45
	225	2010	5.76	156	183	85
	226	2020	5.46	117	143	82
	227	2030	5.18	90	100	90
Back Up	228	2000	5.18	90	237	38
	229	1700	5.52	110	480	23
	230	1420	9.26	463	507	91
	231	1340	9.94	513	523	98
	232	1260	10.11	524	537	98
	233	1210	10.28	533	540	99
	234	1330	10.28	533	527	100
	235	1470	9.67	493	503	98
	236	1550	9.36	483	490	99
	237	1630	9.33	483	480	100
	238	1620	9.33	483	480	100
	239	1700	9.26	477	480	99
	240	1840	9.26	467	480	97
	241	1950	9.23	463	450	100
	242	1980	8.24	390	417	94
	243	2000	6.88	267	237	100
	244	2010	5.86	167	183	91
	245	2000	5.52	124	237	52
	246	1990	5.66	143	387	37
	247	1985	6.37	220	403	55
	248	2000	6.20	199	237	84
	249	2010	5.59	133	183	73

TABLE 6 (cont'd)

	Time Sec	Speed rpm	Rack mm	Torque lb.ft	Maximum Available Torque lb.ft	% of Maximum Torque
Back Up	250	1990	5.52	110	387	28
	251	1985	6.03	183	403	45
	252	1990	6.41	220	387	57
	253	2005	6.03	183	217	84
	254	2000	5.59	133	237	56
	255	1990	5.52	110	387	28
	256	1990	6.13	197	387	51
	257	2000	6.20	199	237	84

TABLE 7

Ignition Improver Specifications

Type		Octyl Nitrate
Product Identification		DII-3
Manufacturer & Supplier		Ethyl Corporation
Form		Liquid
Colour		Pale Yellow
Water % ($^{w}/w$)		0.05
Colour ASTM D 1500		1.0
Acid as HNO % ($^{w}/_{w}$)		0.003
Vapour Pressure mm Hg	@ 20°C	0.2
	@ 82°C	10
	@ 137°C	100
Flash Point TCC °C		72
Freezing Point °C		-50
Density g/mL	@ 20°C	0.9640
Density Correction Factor g/mL/°C		0.00093
Viscosity cSt	@ 20°C	1.8
	@ 0°C	2.7
	@ -29°C	7.7
Solubility in Diesel Fuel @ 20°C		Miscible
Thermal Stability		Decomposition Begins @ 175°C
Percent Ignition Improver Required To Raise Cetane Number of		
40 Cetane No. TO 43		0.062
TO 43		0.145

TABLE 8

Combustion and Injection Characteristics

For 14^o Timing - Diesel Fuel

Engine Speed RPM	Torque		Combustion						Injection					
	Nm	%	Indicated Work Nm	IMEP kPa	P_{max} kPa	CA^o P_{max}	ΔP_{max} kPa	CA^o ΔP_{max}	Start of Pressure Rise CA^o	P_{max} at Negative Slope kPa	CA^o at Negative Slope	End of Injection CA^o	Injection P_{max} kPa	CA^o Injection P_{max}
2300	581	100	1030	644	6850	368	233	361	343	13400	347	386	30200	359
2300	428	75	778	487	7010	368	323	361	343	7790	344	384	28200	353
2300	286	50	615	385	6880	368	314	362	343	13300	347	381	29800	353
2300	144	25	395	248	7100	364	521	362	342	5800	344	379	29870	352
2300	57	10	282	177	6800	364	377	361	342	13619	346	378	25130	352
2100	607	100	1050	658	6800	368	197	361	344	7220	345	385	29500	359
2100	455	75	781	489	7020	368	278	361	343	6980	344	382	27900	352
2100	303	50	582	364	7180	367	350	361	343	8400	344	380	26600	352
2100	152	25	355	222	6850	364	394	362	343	8760	344	377	27700	352
2100	55	9	219	137	7060	363	422	360	342	12500	346	376	19700	353
1900	616	100	972	609	7080	369	251	362	346	7930	347	383	26000	361
1900	461	75	778	488	7490	369	323	361	345	6780	346	381	24100	354
1900	310	50	569	357	7210	368	314	362	345	6760	346	379	25000	354
1900	155	25	333	209	6990	368	350	363	345	12900	349	376	26800	354
1900	53	9	197	123	7150	364	359	362	344	13300	348	374	25400	353
1700	620	100	925	580	7070	370	206	361	346	10000	349	380	23800	354
1700	464	75	726	455	7470	367	269	361	345	7990	349	377	22900	356
1700	310	50	495	310	7390	367	287	361	346	5900	347	376	23200	355
1700	154	25	278	174	7190	367	332	362	346	9670	350	373	23500	354
1700	51	8	150	94.1	6980	364	251	363	346	10200	349	372	24200	354

TABLE 8

Combustion and Injection Characteristics

For 14^{o} Timing - Diesel Fuel

Engine Speed RPM	Torque		Combustion						Injection					
	Nm	%	Indicated Work Nm	IMEP kPa	P_{max} kPa	CA^{o} P_{max}	ΔP_{max} kPa	CA^{o} ΔP_{max}	Start of Pressure Rise CA^{o}	P_{max} at Negative Slope kPa	CA^{o} at Negative Slope	End of Injection CA^{o}	Injection P_{max} kPa	CA^{o} Injection P_{max}
2300	581	100	1030	644	6850	368	233	361	343	13400	347	386	30200	359
2300	428	75	778	487	7010	368	323	361	343	7790	344	384	28200	353
2300	286	50	615	385	6880	368	314	362	343	13300	347	381	29800	353
2300	144	25	395	248	7100	364	521	362	342	5800	344	379	29870	352
2300	57	10	282	177	6800	364	377	361	342	13619	346	378	25130	352
2100	607	100	1050	658	6800	368	197	361	344	7220	345	385	29500	359
2100	455	75	781	489	7020	368	278	361	343	6980	344	382	27900	352
2100	303	50	582	364	7180	367	350	361	343	8400	344	380	26600	352
2100	152	25	355	222	6850	364	394	362	343	8760	344	377	27700	352
2100	55	9	219	137	7060	363	422	360	342	12500	346	376	19700	353
1900	616	100	972	609	7080	369	251	362	346	7930	347	383	26000	361
1900	461	75	778	488	7490	369	323	361	345	6780	346	381	24100	354
1900	310	50	569	357	7210	368	314	362	345	6760	346	379	25000	354
1900	155	25	333	209	6990	368	350	363	345	12900	349	376	26800	354
1900	53	9	197	123	7150	364	359	362	344	13300	348	374	25400	353
1700	620	100	925	580	7070	370	206	361	346	10000	349	380	23800	354
1700	464	75	726	455	7470	367	269	361	345	7990	349	377	22900	356
1700	310	50	495	310	7390	367	287	361	346	5900	347	376	23200	355
1700	154	25	278	174	7190	367	332	362	346	9670	350	373	23500	354
1700	51	8	150	94.1	6980	364	251	363	346	10200	349	372	24200	354

Table 8 (cont'd.)

Combustion and Injection Characteristics

For 14^{o} Timing - Diesel Fuel

Engine Speed RPM	Torque		Combustion						Injection					
	Nm	%	Indicated Work Nm	IMEP kPa	P_{max} kPa	CA^{o} P_{max}	ΔP_{max} kPa	CA^{o} ΔP_{max}	Start of Pressure Rise CA^{o}	P_{max} at Negative Slope kPa	CA^{o} at Negative Slope	End of Injection CA^{o}	Injection P_{max} kPa	CA^{o} Injection P_{max}
1500	660	100	979	613	6390	369	215	361	345	9060	348	380	27500	363
1500	495	75	752	472	6590	370	260	361	345	9080	348	376	23500	360
1500	331	50	518	325	6620	369	314	361	344	7610	347	374	22300	355
1500	162	25	260	163	6290	367	296	361	345	8250	348	371	22500	352
1500	50	8	117	73.4	5930	363	260	362	345	5490	346	370	23000	352
1300	695	100	999	626	6430	367	269	360	345	7120	348	378	29200	361
1300	521	75	758	475	6520	368	278	360	345	6830	348	375	27300	361
1300	348	50	496	311	6540	367	278	360	345	3310	346	377	22100	360
1300	174	25	240	151	6320	366	314	360	345	3920	346	369	21100	352
1300	44	6	65	41	5920	366	296	361	346	6860	349	368	21100	353

TABLE 9

Combustion and Injection Characteristics

For 14^{o} Timing - 12% (^{E}/E) Methanol/Diesel Emulsion

Engine Speed RPM	Torque		Combustion						Injection					
	Nm	%	Indicated Work Nm	IMEP kPa	P_{max} kPa	CA^{o} P_{max}	ΔP_{max} kPa	CA^{o} ΔP_{max}	Start of Pressure Rise CA^{o}	P_{max} at Negative Slope kPa	CA^{o} at Negative Slope	End of Injection CA^{o}	Injection P_{max} kPa	CA^{o} Injection P_{max}
2300	582	100	1072	672	6640	365	314	363	339	7790	346	387	33700	360
2300	426	75	823	516	6880	367	422	364	338	7910	346	385	30400	359
2300	286	50	636	399	6780	369	422	366	338	7520	346	382	30000	354
2300	149	25	441	277	6300	371	269	367	338	7350	346	382	28500	355
2300	59	10	430	270	6360	372	422	369	339	7440	346	381	28900	355
1900	617	100	1010	632	6950	368	206	363	340	6130	347	384	27700	361
1900	464	75	770	483	7030	370	242	362	340	5900	347	382	26500	360
1900	307	50	558	350	7110	365	431	363	340	6100	343	379	25800	352
1900	152	25	351	220	6780	367	359	365	340	5970	347	376	27300	355
1900	54	9	280	176	6730	367	359	365	340	5730	347	376	27100	355
1500	663	100	1010	635	6270	370	314	362	341	4530	348	382	29500	363
1500	494	75	745	467	6350	370	341	364	349	4430	346	376	25600	363
1500	331	50	503	315	6410	368	395	363	340	4530	346	375	22800	352
1500	161	25	265	166	6040	368	341	364	340	4550	346	372	24100	353
1500	51	8	129	81	5480	369	161	365	340	4550	346	370	23300	353
REPEAT TESTS														
1900	311	50	653	409	7340	370	368	363	340	6150	347	380	25700	354
1900	156	25	438	275	7130	368	449	365	340	5900	347	377	28400	355
1500	330	50	516	323	6580	369	305	364	340	4630	346	375	22800	352
1500	163	25	269	169	6230	369	314	366	340	4650	346	372	24200	353

TABLE 10

Combustion and Injection Characteristics

For 14^{o} Timing - 12% ($^{E}/E$) Methanol/Diesel Emulsion - With Glow Plug Heat

Engine Speed RPM	Torque		Combustion						Injection					
	Nm	%	Indicated Work Nm	IMEP kPa	P_{max} kPa	CA^{o} P_{max}	ΔP_{max} kPa	CA^{o} ΔP_{max}	Start of Pressure Rise CA^{o}	P_{max} at Negative Slope kPa	CA^{o} at Negative Slope	End of Injection CA^{o}	Injection P_{max} kPa	CA^{o} Injection P_{max}
2300	583	100	1060	662	6630	365	332	362	338	7690	345	386	33500	360
2300	429	75	820	514	7170	366	583	363	338	7810	346	384	31300	359
2300	287	50	740	464	7070	367	449	364	338	7660	345	383	29200	353
2300	147	25	505	317	6790	370	503	367	338	7320	345	381	30600	354
2300	56	10	461	289	6650	371	377	368	338	7220	345	381	29200	354
1500	668	100	1010	634	6360	370	359	362	341	4630	346	381	29700	363
1500	492	75	739	463	6410	368	377	363	340	4580	346	377	25000	363
1500	330	50	498	312	6540	368	359	363	340	4680	346	374	23200	352
1500	163	25	264	165	6020	369	287	365	340	4770	346	372	24400	353

Note - Glow Plug Heat 35 AMPS @ 8 VDC

TABLE 11

Combustion and Injection Characteristics

For 17^{o} Timing - Diesel Fuel

Engine Speed RPM	Torque		Combustion						Injection					
	Nm	%	Indicated Work Nm	IMEP kPa	P_{max} kPa	CA^{o} P_{max}	ΔP_{max} kPa	CA^{o} ΔP_{max}	Start of Pressure Rise CA^{o}	P_{max} at Negative Slope kPa	CA^{o} at Negative Slope	End of Injection CA^{o}	Injection P_{max} kPa	CA^{o} Injection P_{max}
2300	581	100	1050	657	7490	367	296	358	340	14700	344	383	32100	356
2300	428	75	805	504	7410	366	350	358	340	13600	344	381	29400	350
2300	286	50	605	379	7370	366	368	358	340	14500	344	379	29600	350
2300	149	25	393	246	7280	365	610	358	340	13100	344	377	29000	350
2300	57	10	297	186	7320	361	673	358	340	12900	344	376	26500	350
1900	619	100	1020	639	7680	368	188	360	343	12800	347	380	28600	358
1900	463	75	784	491	7840	367	206	358	343	13300	346	378	26500	351
1900	307	50	544	341	7810	366	269	359	342	12900	346	376	26100	351
1900	153	25	318	199	7410	366	251	360	343	12600	346	373	24800	352
1900	56	9	186	117	7120	365	260	359	342	13100	346	372	24800	351
1500	666	100	1010	636	6960	367	206	359	342	8970	346	376	28800	360
1500	492	75	753	472	7050	367	215	358	342	10400	345	373	23800	349
1500	330	50	511	320	7070	366	269	357	342	8570	345	371	22900	349
1500	162	25	247	155	6710	364	449	358	342	9700	345	369	23200	369
1500	51	8	103	64	6390	364	404	359	342	9990	345	364	22400	350
720	33		-86	-54	6030	361	296	355	341			360	18200	351

TABLE 12

Combustion and Injection Characteristics

For 20^{O} Timing - Diesel Fuel

Engine Speed RPM	Torque		Combustion						Injection					
	Nm	%	Indicated Work Nm	IMEP kPa	P_{max} kPa	CA^{O} P_{max}	ΔP_{max} kPa	CA^{O} ΔP_{max}	Start of Pressure Rise CA^{O}	P_{max} at Negative Slope kPa	CA^{O} at Negative Slope	End of Injection CA^{O}	Injection P_{max} kPa	CA^{O} Injection P_{max}
2300	583	100	1030	645	8020	365	619	355	337	13300	342	381	32300	354
2300	428	75	794	498	8160	365	844	355	338	14100	342	378	29400	350
2300	287	50	587	368	8170	364	817	356	338	14900	342	376	29800	348
2300	149	25	373	234	7962	358	996	356	337	14100	341	374	29000	347
2300	58	10	291	182	8000	358	1070	356	337	14300	341	373	27500	347
1900	620	100	1000	627	8410	365	305	354	340	14300	344	378	27700	355
1900	463	75	782	490	8520	366	422	355	339	13600	343	375	26100	350
1900	306	50	554	347	8340	365	422	355	339	12900	343	373	27100	348
1900	151	25	322	202	8080	364	548	356	340	12900	343	371	24800	349
1900	56	9	194	121	7580	363	575	356	340	13400	343	370	26300	348
1500	665	100	1010	635	7520	364	305	355	340	8370	343	374	29300	357
1500	494	75	478	469	7590	365	323	354	339	10200	342	370	22700	347
1500	330	50	512	321	7560	365	449	355	339	9280	342	368	23400	346
1500	163	25	246	154	7150	362	610	355	339	9560	342	375	23300	347
1500	51	8	96	60	6820	361	691	356	340	9970	342	373	22800	347
717	33		-85	-53	6350	359	359	352	338	17200	344	357	18200	349

TABLE 13

Combustion and Injection Characteristics

For 17^{o} Timing - 12% (^{E}/E) Methanol/Diesel Emuslion

Engine Speed RPM	Torque		Combustion							
	Nm	%	Indicated Work Nm	IMEP kPa	P_{max} kPa	CA^{o} P_{max}	ΔP_{max} kPa/CA^{o}	CA^{o} ΔP_{max}	Start of Pressure Rise CA^{o}	End of Injection CA^{o}
2300	584	100	1062	666	7470	363	637	361	336	385
2300	427	75	821	514	7740	365	817	362	336	382
2300	285	50	640	401	7830	367	772	364	336	380
2300	151	25	445	279	7110	369	557	367	334	379
2300	56	10	345	216	6310	371	341	368	336	379
1900	619	100	1062	644	7480	369	377	361	338	381
1900	464	75	791	496	7690	369	467	361	337	379
1900	306	50	549	344	7810	364	682	361	337	376
1900	151	25	340	213	7520	365	521	363	338	374
1900	55	9	265	166	7390	365	601	363	338	374
1500	664	100	1020	640	7120	368	494	360	338	379
1500	494	75	754	473	7070	368	503	362	338	375
1500	329	50	505	317	7080	367	539	362	338	372
1500	162	25	270	169	6710	364	575	362	338	369
1500	49	8	125	78	6180	366	404	362	338	367
683	31	-	-67	-42	6032	361	260	357	339	360

TABLE 14

Combustion and Injection Characteristics

For 20° Timing - 12% (E/E) Methanol/Diesel Emulsion

Engine Speed RPM	Torque		Combustion						Injection					
	Nm	%	Indicated Work Nm	IMEP kPa	P_{max} kPa	CA° P_{max}	ΔP_{max} kPa	CA° ΔP_{max}	Start of Pressure Rise CA°	P_{max} at Negative Slope kPa	CA° at Negative Slope	End of Injection CA°	Injection P_{max} kPa	CA° Injection P_{max}
2300	583	100	1030	644	8310	359	1260	357	333	8280	340	380	34100	354
2300	428	75	761	477	8940	360	1420	358	333	8180	340	379	30800	354
2300	287	50	608	381	9140	362	1500	361	333	7960	340	377	30600	349
2300	149	25	412	258	8480	363	1220	362	333	7790	340	376	30000	349
2300	58	10	318	200	7400	366	691	364	333	7890	340	378	25700	350
1900	620	100	1012	634	8400	367	880	358	335	6570	341	378	28800	355
1900	463	75	757	475	8550	366	871	358	334	6110	341	376	26600	348
1900	306	50	524	328	8740	361	1100	359	334	6760	341	373	26400	348
1900	151	25	322	202	8380	362	969	360	334	6290	341	371	28900	349
1900	56	9	203	127	8240	362	1040	360	334	6300	341	371	26300	349
1500	665	100	996	624	7810	365	772	358	335	5070	341	376	29600	357
1500	494	75	728	456	7910	365	907	358	335	4800	341	371	25800	357
1500	330	50	491	308	7850	364	1090	359	335	4930	341	369	23800	347
1500	163	25	251	158	7680	361	1010	359	335	5020	340	366	24300	347
683	30		-93	-58	6220	360	377	355	336	-	-	363	19200	351

TABLE 15

Combustion and Injection Characteristics

For 17° Timing - 12% ($^E/E$) Methanol/Diesel Emulsion
With Glow Plug Heat

Engine Speed RPM	Torque		Combustion							
	Nm	%	Indicated Work Nm	IMEP kPa	P_{max} kPa	CA° P_{max}	ΔP_{max} kPa/CA°	CA° ΔP_{max}	Start of Pressure Rise CA°	End of Injection CA°
2300	584	100	1070	671	7470	364	628	361	337	385
2300	427	75	823	516	7640	364	790	362	336	382
2300	285	50	650	407	7570	367	781	365	336	381
2300	151	25	440	276	7300	369	745	367	336	379
2300	56	10	363	228	6550	371	431	368	336	379
1900	619	100	1030	645	7540	368	422	360	338	381
1900	464	75	788	494	7680	369	485	361	337	379
1900	306	50	552	346	7850	364	736	362	337	376
1900	151	25	340	213	7680	365	664	363	338	374
1900	55	9	272	171	7580	365	745	363	338	373
1500	664	100	1020	639	7040	368	467	360	338	379
1500	494	75	751	471	7010	368	458	362	338	375
1500	329	50	511	320	7080	366	521	363	338	372
1500	162	25	269	168	6620	366	467	362	338	369
1500	49	8	125	78	6110	366	332	363	338	367

Note: Glow Plug Heat 35 AMPS @ 8 VDC

TABLE 16

Combustion and Injection Characteristics

For 20° Timing - 12% (E/E) Methanol/Diesel Emulsion - with Glow Plug Heat

Engine Speed RPM	Torque		Combustion						Injection					
	Nm	%	Indicated Work Nm	IMEP kPa	P_{max} kPa	CA° P_{max}	ΔP_{max} kPa	CA° ΔP_{max}	Start of Pressure Rise CA°	P_{max} at Negative Slope kPa	CA° at Negative Slope	End of Injection CA°	Injection P_{max} kPa	CA° Injection P_{max}
2300	583	100	1270	799	8040	368	628	359	334	7730	343	385	30600	364
2300	428	75	769	482	8820	361	1290	359	333	8070	346	379	30900	354
2300	287	50	610	383	8670	363	1290	361	333	8000	340	377	30600	349
2300	149	25	414	260	8330	364	1240	362	333	7790	340	376	30000	349
2300	58	10	306	192	7320	367	583	364	333	7860	340	378	25400	350
1900	620	100	997	625	8400	367	808	357	335	6590	341	378	29000	355
1900	463	75	768	481	8440	367	969	358	334	6660	341	376	26600	349
1900	306	50	528	331	8350	365	1010	359	334	6650	341	374	26500	348
1900	151	25	325	204	8690	362	1130	360	334	6260	341	371	29500	349
1900	56	9	204	128	8220	362	987	360	334	6240	341	371	26100	349
1500	665	100	992	622	7790	365	628	358	335	4990	341	376	29400	357
1500	494	75	732	459	7910	365	898	359	335	4790	341	371	25800	357
1500	330	50	493	308	7860	365	987	359	335	4820	341	369	23700	347
1500	163	25	255	160	7830	362	1220	360	335	4960	340	366	24200	347

Note: Glow Plug Heat 35 Amps @ 8 VDC

TABLE 17

Combustion and Injection Characteristics
For 14° Timing - 15% $(^E/E)$ Methanol/Diesel Emulsion
With 1.5% $(^V/V)$ Cetane Improver

Engine Speed RPM	Torque		Combustion						Injection	
	Nm	%	Indicated Work Nm	IMEP kPa	P_{max} kPa	CA° P_{max}	ΔP_{max} kPa/CA°	CA° ΔP_{max}	Start of Pressure Rise CA°	End of Injection CA°
2300	427	75	816	511	6590	369	224	362	339	386
2300	286	50	610	382	6380	369	215	365	339	384
2300	150	25	433	272	6010	370	180	368	339	384
2300	54	10	336	211	5840	356	90	368	339	385
1900	465	75	784	491	6760	370	117	363	341	383
1900	153	25	314	197	6570	367	278	365	341	378
1500	163	25	246	154	5740	366	296	364	341	373

TABLE 18

Combustion and Injection Characteristics

For 14^{o} Timing - 15% ($^{E}/E$) Methanol/Diesel Emulsion
With 3% ($^{V}/V$) Cetane Improver

Engine Speed RPM	Torque		Combustion						Injection	
	Nm	%	Indicated Work Nm	IMEP kPa	P_{max} kPa	CA^{o} P_{max}	ΔP_{max} kPa/CA^{o}	CA^{o} ΔP_{max}	Start of Pressure Rise CA^{o}	End of Injection CA^{o}
2300	427	75	810	508	6520	369	153	362	339	386
2300	286	50	603	378	6330	370	180	363	339	384
2300	150	25	393	246	5970	367	197	366	339	384
2300	57	10	294	185	5840	356	171	367	339	386
1900	465	75	779	489	6780	370	144	363	341	383
1900	154	25	315	198	6550	366	224	364	341	378
1500	162	25	257	161	5870	364	305	362	341	373

TABLE 19

Combustion and Injection Characteristics For 14^o Timing - 15%$_V$ (^{E}/E) Methanol/Diesel Emulsion With 4.5% (^{V}/V) Cetane Improver

Engine Speed RPM	Torque		Combustion						Injection	
	Nm	%	Indicated Work Nm	IMEP kPa	P_{max} kPa	CA^o P_{max}	ΔP_{max} kPa/CA^o	CA^o ΔP_{max}	Start of Pressure Rise CA^o	End of Injection CA^o
2300	426	75	814	510	6400	366	171	363	-	-
2300	288	50	589	369	6180	366	144	360	-	-
2300	286	50	590	370	3600	370	251	363	339	384
2300	149	25	397	249	5810	367	162	365	340	384

TABLE 20

Fuel Consumption Characterization

For 14° Timing - Diesel Fuel

			Mass Basis	Energy Basis
Engine Speed RPM	Torque		Diesel Consumption g/s	Diesel Consumption kJ/s
	Nm	%		
2300	581	100	10.1	458
2300	428	75	7.9	358
2300	286	50	6.0	272
2300	144	25	4.3	195
2300	57	10	3.6	163
2100	607	100	9.3	422
2100	455	75	7.1	322
2100	303	50	5.4	245
2100	152	25	3.9	177
2100	55	9	3.0	136
1900	616	100	8.3	376
1900	461	75	6.3	286
1900	310	50	4.7	213
1900	155	25	3.4	154
1900	53	9	2.6	118
1700	620	100	7.4	336
1700	464	75	5.6	254
1700	310	50	4.2	191
1700	154	25	3.0	136
1700	51	8	2.3	104

TABLE 20 (cont'd.)

Fuel Consumption Characterization

For 14^{o} Timing - Diesel Fuel

			Mass Basis	Energy Basis
Engine Speed RPM	Torque		Diesel Consumption g/s	Diesel Consumption kJ/s
	Nm	%		
1500	660	100	6.7	304
1500	495	75	5.1	231
1500	331	50	3.7	168
1500	162	25	2.5	113
1500	50	8	1.8	81.6
1300	695	100	6.1	277
1300	521	75	4.5	204
1300	348	50	3.2	145
1300	174	25	2.2	99.8
1300	44	6	1.5	68.0

TABLE 21

Fuel Consumption Characterization

For 17^0 Timing - Diesel Fuel

			Mass Basis	Energy Basis
Engine Speed RPM	Torque		Diesel Consumption g/s	Diesel Consumption kJ/s
	Nm	%		
2300	581	100	10.3	467
2300	428	75	8.0	363
2300	286	50	6.2	281
2300	149	25	4.5	204
2300	57	10	3.5	159
1900	619	100	8.4	381
1900	463	75	6.5	295
1900	307	50	4.9	222
1900	153	25	3.5	159
1900	56	9	2.6	118
1500	666	100	6.9	313
1500	492	75	5.2	236
1500	330	50	3.9	177
1500	162	25	2.6	118
1500	51	8	1.8	81.6
720	33	-	0.7	31.8

TABLE 22

Fuel Consumption Characterization

For 20^{0} Timing - Diesel Fuel

			Mass Basis	Energy Basis
Engine Speed RPM	Torque		Diesel Consumption g/s	Diesel Consumption kJ/s
	Nm	%		
2300	583	100	10.2	463
2300	428	75	7.9	358
2300	287	50	6.2	281
2300	149	25	4.6	209
2300	58	10	3.6	163
1900	620	100	8.3	376
1900	463	75	6.5	295
1900	306	50	4.9	222
1900	151	25	3.5	159
1900	56	9	2.6	118
1500	665	100	6.9	313
1500	494	75	5.2	236
1500	330	50	3.9	177
1500	163	25	2.6	118
1500	51	8	1.8	81.6
717	33	-	0.7	31.7

TABLE 23

Fuel Consumption Characteristics

For 14^0 Timing - 12% ($^E/E$) Methanol Diesel Emulsion

			Mass Basis			Energy Basis		
Engine Speed RPM	Torque		Diesel Consumption g/s	Methanol Consumption g/s	Total Fuel Consumption g/s	Diesel Consumption kJ/S	Methanol Consumption kJ/S	Total Fuel Consumption kJ/s
	Nm	%						
2300	582	100	9.4	2.60	12.0	426	59.0	485
2300	426	75	7.3	2.20	9.5	331	49.9	381
2300	286	50	5.8	1.75	7.6	263	39.7	303
2300	149	25	4.6	1.15	5.8	209	26.1	235
2300	59	10	4.4	1.11	5.5	200	25.2	225
1900	617	100	7.7	2.08	9.8	349	47.2	396
1900	464	75	6.0	1.64	7.6	272	37.2	309
1900	307	50	4.9	1.29	6.2	222	29.3	251
1900	152	25	3.4	0.88	4.3	154	20.0	174
1900	54	9	2.8	0.67	3.5	127	15.2	142
1500	663	100	6.0	1.87	7.9	272	42.4	314
1500	494	75	4.5	1.48	6.0	204	33.6	238
1500	331	50	3.4	1.01	4.4	154	22.9	177
1500	161	25	2.3	0.62	2.9	104	14.1	118
1500	51	8	1.6	0.45	2.0	72.6	10.2	83

TABLE 23 (cont'd.)

Fuel Consumption Characteristics
For 14^{o} Timing - 12% (^{E}/E) Methanol Diesel Emulsion

			Mass Basis			Energy Basis		
Engine Speed RPM	Torque		Diesel Consumption g/s	Methanol Consumption g/s	Total Fuel Consumption g/s	Diesel Consumption kJ/S	Methanol Consumption kJ/S	Total Fuel Consumption kJ/s
	Nm	%						
REPEAT	TESTS							
1900	311	50	5.0	1.34	6.3	227	30.4	257
1900	156	25	3.8	0.92	4.7	172	20.9	193
1500	330	50	3.4	1.08	4.5	154	24.5	179
1500	163	25	2.3	0.74	3.0	104	16.8	121

TABLE 24

Fuel Consumption Characteristics
For 14° Timing - 12% $(^{E}/E)$ Methanol Diesel Emulsion
With Glow Plug Heat

			Mass Basis			Energy Basis		
Engine Speed RPM	Torque		Diesel Consumption g/s	Methanol Consumption g/s	Total Fuel Consumption g/s	Diesel Consumption kJ/S	Methanol Consumption kJ/S	Total Fuel Consumption kJ/s
	Nm	%						
2300	583	100	9.4	2.51	11.9	426	57.0	483
2300	429	75	7.3	2.06	9.4	331	46.8	378
2300	287	50	6.8	1.71	8.5	308	28.8	347
2300	147	25	4.9	1.13	6.0	222	25.7	248
2300	56	10	4.6	1.13	5.7	209	25.7	235
1500	668	100	6.0	1.82	7.8	272	41.3	313
1500	492	75	4.5	1.36	5.9	204	30.9	235
1500	330	50	3.4	1.03	4.4	154	23.4	177
1500	163	25	2.2	0.74	2.9	99.8	16.8	117

Note: Glow Plug Heat 35 AMS @ 8 VDC

TABLE 25

Fuel Consumption Characteristics

For 17^{o} Timing - 12% $(^{E}/E)$ Methanol/Diesel Emulsion

With and Without Glow Plug Heat

Engine Speed RPM	Torque		Mass Basis			Energy Basis		
	Nm	%	Diesel Consumption g/s	Methanol Consumption g/s	Total Fuel Consumption g/s	Diesel Consumption kJ/S	Methanol Consumption kJ/S	Total Fuel Consumption kJ/s
2300	584	100	9.2	2.55	11.8	417	57.9	475
2300	427	75	7.2	2.14	9.3	327	48.6	376
2300	285	50	5.7	1.73	7.4	259	39.3	298
2300	151	25	4.3	1.16	5.5	195	26.3	221
2300	56	10	3.6	1.06	4.7	163	24.1	187
1900	619	100	7.6	2.01	9.6	345	45.6	391
1900	464	75	5.9	1.66	7.6	268	37.7	306
1900	306	50	4.5	1.26	5.8	204	28.6	233
1900	151	25	3.2	0.86	4.1	145	19.5	164
1900	55	9	2.7	0.72	3.4	122	16.3	138
1500	664	100	6.0	1.80	7.8	272	40.9	313
1500	494	75	4.5	1.44	5.9	204	32.7	237
1500	329	50	3.4	1.02	4.4	154	23.2	177
1500	162	25	2.4	0.63	3.0	109	14.3	123
1500	49	8	1.6	0.49	2.1	72.5	11.1	83.6
683	31	-	0.8	0.18	1.0	36.3	4.1	40.4

TABLE 26

Fuel Consumption Characteristics

For 20^o Timing - 12% $(^E/E)$ Methanol Diesel Emulsion

With and Without Glow Plug Heat

			Mass Basis			Energy Basis		
Engine Speed RPM	Torque		Diesel Consumption g/s	Methanol Consumption g/s	Total Fuel Consumption g/s	Diesel Consumption kJ/S	Methanol Consumption kJ/S	Total Fuel Consumption kJ/s
	Nm	%						
2300	583	100	9.1	2.47	11.6	413	56.1	469
2300	428	75	7.2	2.03	9.2	327	46.1	373
2300	287	50	5.7	1.73	7.4	259	39.3	298
2300	149	25	4.3	1.10	5.4	195	25.0	220
2300	58	10	3.3	0.97	4.3	150	22.0	172
1900	620	100	7.5	2.06	9.6	340	46.8	387
1900	463	75	5.9	1.64	7.5	268	37.2	305
1900	306	50	4.5	1.24	5.7	204	28.1	232
1900	151	25	3.3	0.88	4.2	150	20.0	170
1900	56	9	2.4	0.63	3.0	109	14.3	123
1500	665	100	6.0	1.83	7.8	272	41.5	314
1500	494	75	4.5	1.41	5.9	204	32.0	236
1500	330	50	3.5	1.01	4.5	159	22.9	182
1500	163	25	2.3	0.77	3.1	104	17.5	122

TABLE 27

Fuel Consumption Characteristics

For 20° Timing - 12% ($^{E}/E$) Methanol Diesel Emulsion

With and Without Glow Plug Heat

			Mass Basis			Energy Basis		
Engine Speed RPM	Torque		Diesel Consumption g/s	Methanol Consumption g/s	Total Fuel Consumption g/s	Diesel Consumption kJ/S	Methanol Consumption kJ/S	Total Fuel Consumption kJ/s
	Nm	%						
2300	583	100	9.1	2.47	11.6	413	56.1	469
2300	428	75	7.2	2.03	9.2	327	46.1	373
2300	287	50	5.7	1.73	7.4	259	39.3	298
2300	149	25	4.3	1.10	5.4	195	25.0	220
2300	58	10	3.3	0.97	4.3	150	22.0	172
1900	620	100	7.5	2.06	9.6	340	46.8	387
1900	463	75	5.9	1.64	7.5	268	37.2	305
1900	306	50	4.5	1.24	5.7	204	28.1	232
1900	151	25	3.3	0.88	4.2	150	20.0	170
1900	56	9	2.4	0.63	3.0	109	14.3	123
1500	665	100	6.0	1.83	7.8	272	41.5	314
1500	494	75	4.5	1.41	5.9	204	32.0	236
1500	330	50	3.5	1.01	4.5	159	22.9	182
1500	163	25	2.3	0.77	3.1	104	17.5	122

TABLE 28

Fuel Consumption Characteristics

For 14^{o} Timing - 15% (^{E}/E) Methanol Diesel Emulsion and Three Concentrations of Ignition Improver

			Mass Basis			Energy Basis		
Engine Speed RPM	Torque Nm	Torque %	Diesel Consumption g/s	Methanol Consumption g/s	Total Fuel Consumption g/s	Diesel Consumption kJ/S	Methanol Consumption kJ/S	Total Fuel Consumption kJ/s
4.5% (^{V}/V) Ignition Improver								
2300	426	75	6.5	3.40	9.9	295	77.2	372
2300	288	50	4.9	2.26	7.2	222	51.3	273
2300	288	50	5.2	1.70	6.9	236	38.6	275
2300	149	25	4.0	1.11	5.1	181	25.2	206
3.0% (^{V}/V) Ignition Improver								
2300	427	75	6.6	2.84	9.4	299	64.5	364
2300	286	50	5.0	2.23	7.2	227	50.6	278
2300	150	25	3.8	1.70	5.5	172	38.6	211
2300	57	10	3.0	1.31	4.3	136	29.7	166
1900	465	75	5.4	2.32	7.7	245	52.7	298
1900	154	25	2.8	1.20	4.0	127	27.2	154
1500	162	25	2.1	0.93	3.0	95.3	21.1	116

cont'd.

TABLE 28 (cont'd.)

Fuel Consumption Characteristics

For 14^{o} Timing - 15% (^{E}/E) Methanol Diesel Emulsion and Three Concentrations of Ignition Improver

Engine Speed RPM	Torque		Mass Basis			Energy Basis		
	Nm	%	Diesel Consumption g/s	Methanol Consumption g/s	Total Fuel Consumption g/s	Diesel Consumption kJ/S	Methanol Consumption kJ/S	Total Fuel Consumption kJ/s
1.5% (^{V}/V) Ignition Improver								
2300	427	75	6.6	2.87	9.5	299	65.1	364
2300	286	50	5.2	2.32	7.5	236	52.7	289
2300	150	25	4.1	1.80	5.9	186	40.9	227
2300	57	10	3.2	1.34	4.5	145	30.4	175
1900	465	75	5.5	2.37	7.9	249	53.8	303
1900	154	25	2.9	1.26	4.2	132	28.6	161
1500	162	25	2.1	9.03	3.0	95.3	21.1	116

TABLE 29

Particulate Concentrations (mg/m^3) - Steady State Testing

Engine Speed RPM	Engine Load kW	% Load of Maximum	Insoluble Particulate mg/m^3		Soluble Particulate mg/m^3		Total Particulate mg/m^3	
			Diesel	Emulsion	Diesel	Emuslion	Diesel	Emulsion
2300	139	100	50.2	21.8	9.3	8.9	59.5	30.7
2300	103	75	22.6	9.8	21.6	25.1	44.3	34.9
2300	69	50	13.7	6.6	55.4	48.2	69.1	54.8
2300	35	25	12.2	3.9	74.6	104.0	86.8	107.9
1900	122	100	64.9	18.6	12.5	15.4	77.4	34.0
1900	91	75	27.8	7.7	44.2	48.4	72.0	56.1
1900	61	50	10.6	4.3	66.5	84.5	77.1	88.8
1900	31	25	7.8	3.7	62.1	83.9	69.9	87.6
1500	103	100	57.7	21.5	7.4	7.8	65.1	29.3
1500	77	75	14.3	5.6	33.6	24.8	47.8	30.4
1500	52	50	9.4	3.8	39.6	42.6	49.0	46.4
1500	26	25	7.7	0.72	34.7	52.5	42.4	53.2

TABLE 30

Effects of Methanol/Diesel Emusion
On Particulate Emissions*
Steady State Testing

Engine Speed RPM	Engine Load kW	% Load of Maximum	% Change in Insoluble Particulates	% Change in Soluble Particulates	% Change in Total Particulates
2300	139	100	- 56.6	- 4.3	- 48.4
2300	103	75	- 56.6	+ 16.2	- 21.2
2300	69	50	- 51.8	- 13.0	- 20.7
2300	35	25	- 68.0	+ 39.4	+ 24.3
1900	122	100	- 71.3	+ 23.2	- 56.1
1900	91	75	- 72.3	+ 9.5	- 22.1
1900	61	50	- 59.4	+ 27.1	+ 15.2
1900	31	25	- 52.6	+ 35.1	+ 25.3
1500	103	100	- 62.7	+ 5.4	- 55.0
1500	77	75	- 60.8	- 26.2	- 36.4
1500	52	50	- 59.6	+ 7.6	- 5.3
1500	26	25	- 90.6	+ 51.3	+ 25.5

Notes: 1. *Calculations based on emissions in mg/m^3 from Table

2. Changes are relative to Neat Diesel Particulate Emissions.

TABLE 31

Particulate Emission Rates (g/h) - SteadyState Testing

Engine Speed RPM	Engine Load kW	% Load of Maximum	Insoluble Particulate g/h		Soluble Particulate g/h		Total Particulate g/h	
			Diesel	Emulsion	Diesel	Emuslion	Diesel	Emulsion
2300	139	100	32.6	13.7	6.0	5.6	38.6	19.3
2300	103	75	14.0	6.3	13.4	16.0	27.4	22.3
2300	69	50	9.3	4.5	37.5	32.6	46.8	37.1
2300	35	25	9.3	3.0	56.9	79.3	66.2	82.3
1900	122	100	35.1	9.5	6.8	7.8	41.9	17.3
1900	91	75	14.7	4.0	23.4	25.3	38.1	29.3
1900	61	50	6.2	2.3	38.9	46.5	45.1	48.8
1900	31	25	4.8	2.1	38.0	50.2	42.8	52.3
1500	103	100	26.4	8.9	3.4	4.9	29.8	13.8
1500	77	75	6.0	2.7	14.1	11.9	20.1	14.6
1500	52	50	4.8	1.8	20.1	20.6	24.9	22.4
1500	26	25	3.6	0.4	16.1	28.4	19.7	28.8

TABLE 32

Load Specific Particulate Emission Rates (g/kW.h) - Steady State Testing

Engine Speed RPM	Engine Load kW	% Load of Maximum	Insoluble Particulate g/kW.h		Soluble Particulate g/kW.h		Total Particulate g/kW.h	
			Diesel	Emulsion	Diesel	Emuslion	Diesel	Emulsion
2300	139	100	0.23	0.098	0.04	0.04	0.28	0.14
2300	103	75	0.14	0.061	0.13	0.16	0.27	0.22
2300	69	50	0.14	0.065	0.55	0.47	0.68	0.54
2300	35	25	0.27	0.086	1.64	2.27	1.89	2.35
1900	122	100	0.29	0.078	0.06	0.06	0.34	0.14
1900	91	75	0.16	0.044	0.26	0.28	0.42	0.32
1900	61	50	0.10	0.038	0.63	0.76	0.74	0.80
1900	31	25	0.16	0.070	1.24	1.63	1.38	1.69
1500	103	100	0.26	0.086	0.03	0.03	0.29	0.13
1500	77	75	0.08	0.035	0.18	0.15	0.26	0.19
1500	52	50	0.09	0.036	0.39	0.40	0.48	0.43
1500	26	25	0.14	0.105	0.62	1.10	0.76	1.11

TABLE 33

Gaseous Emissions Concentrations - Steady State Testing

Engine Speed RPM	Engine Load kW	% Load of Maximum	CO_2 %		CO ppm		THC* ppm		NO ppm		NO_2 ppm		NO_x ppm	
			Diesel	Emulsion	Diesel	Emulsion	Diesel	Emulsion	Diesel	Emulsion	Diesel	Emulsion	Diesel	Emulsion
2300	139	100	9.8	9.5	302	237	111	119	651	524	37	32	688	556
2300	103	75	7.8	7.1	173	150	87	113	647	470	11	44	658	514
2300	69	50	5.9	5.4	156	176	111	153	494	359	20	39	514	398
2300	35	25	4.3	4.0	126	242	96	382	347	246	26	37	373	283
1900	122	100	9.3	8.9	297	168	150	147	694	567	5	27	699	594
1900	91	75	7.4	7.0	161	155	110	136	670	488	12	37	682	525
1900	61	50	5.4	5.1	128	152	105	181	511	373	6	45	517	418
1900	31	25	3.7	3.3	131	174	96	138	341	229	5	52	346	281
1500	103	100	8.8	8.5	151	103	105	43		535		13		548
1500	77	75		6.3		71		104		472		24		496
1500	52	50		4.6		72		84		413		36		449
1500	26	25	3.2	3.0	76	113	60	78		243		23		266

* THC - expressed as equivalent methane.

Note: NO and NO_2 data not available due to NO_x convertor malfunction.

TABLE 34

Gaseous Mass Emissions (g/h) - Steady State Testing

Engine Speed RPM	Engine Load kW	% Load of Maximum	CO g/h		THC g/h		NO g/h		NO_2 g/h		NO_x as NO_2 g/h	
			Diesel	Emulsion	Diesel	Emulsion	Diesel	Emulsion	Diesel	Emulsion	Diesel	Emulsion
2300	139	100	225	174	48	50	527	424	46	40	854	691
2300	103	75	131	112	38	48	500	363	13	52	779	609
2300	69	50	125	136	51	67	418	304	26	51	667	517
2300	35	25	107	181	47	164	331	234	38	54	545	413
1900	122	100	185	101	54	50	469	383	5	28	725	616
1900	91	75	105	96	41	48	443	323	12	38	691	532
1900	61	50	84	99	40	67	374	273	7	50	580	469
1900	31	25	90	121	38	55	261	175	6	61	406	330
1500	103	100	81	50	32	12		306		11		481
1500	77	75	47	40	22	34		248		19		400
1500	52	50	37	42	20	28		262		35		437
1500	26	25	45	74	21	29		141		21		237

TABLE 35

Effects of Methanol/Diesel Emulsion on Gaseous Emissions Steady State Testing

Engine Speed RPM	Engine Load kW	% Load of Maximum	% Change in CO Emissions	% Change in THC Emissions	% Change in NO Emissions	% Change in NO_2 Emissions	% Change* in NO_x Emissions
2300	139	100	- 22.7	+ 4.2	- 19.0	- 13.0	- 19.0
2300	103	75	- 14.5	+ 26.3	- 27.0	+300.0	- 22.0
2300	69	50	+ 8.8	+ 31.3	- 27.0	+ 96.0	- 22.0
2300	35	25	+ 69.2	+248.0	- 29.0	+ 42.0	- 24.0
1900	122	100	- 45.4	- 7.4	- 18.0	+460.0	- 15.0
1900	91	75	- 8.6	+ 17.0	- 27.0	+216.0	- 23.0
1900	61	50	+ 17.9	+ 67.5	- 27.0	+614.0	- 19.0
1900	31	25	+ 34.4	+ 44.7	- 33.0	+916.0	+ 19.0
1500	103	100	- 38.3	- 62.3	-	-	
1500	77	75	- 14.9	+ 54.5	-	-	
1500	52	50	+ 13.5	+ 40.0	-	-	
1500	26	25	+ 64.4	+ 38.1	-	-	

* Based on g/h as NO_2

TABLE 36

Aldehyde Concentrations
Steady State Testing With Diesel Fuel

Compound		Speed (RPM)	2300	2300	2300	1900	1900	1900
		Load (kW)	103	69	35	91	61	31
Formaldehyde	μg/m^3		14000	17600	13800	11400	9980	5400
	ppm		11.20	14.07	11.07	9.13	8.00	4.30
Acetaldehyde	μg/m^3		5200	7070	5500	4230	4160	2570
	ppm		2.82	3.85	3.02	2.30	2.26	1.39
Acetone[3]	μg/m^3							
	ppm							
Isobutraldehyde	μg/m^3		1460	393	860	630	648	< DL
+ Methyl Ethyl Ketone	ppm		0.49	0.15	0.27	0.22	0.20	
Crotonaldehyde	μg/m^3		485	426	720	279	267	30.3
	ppm		0.15	0.15	0.22	0.09	0.08	< 0.01
Hexanaldehyde[1]	μg/m^3		< DL[2]	< DL	< DL	< DL	< DL	< DL
	ppm							
Benzaldehyde	μg/m^3		< DL	< DL	< DL	< DL	< DL	< DL
	ppm							
Total Aldehydes	μg/m^3		21100	25500	20900	16500	15000	8000
	ppm		14.7	18.2	14.6	11.7	10.6	5.7
% Formaldehyde of Total			66%	69%	66%	69%	67%	68%

Note: 1. Approximate Detection Limits
for Hexanaldehyde = 200 μg/m^3 (0.05 ppm)
for Benzaldehyde = 169 μg/m^3 (0.05 ppm)

2. DL = Detection Limit

3. Suspected contamination of sample with acetone prevented accurate acetone analysis.

TABLE 37

Aldehyde Concentrations
Steady State Testing With Emulsion

Compound		Speed (RPM) - 2300	2300	2300	1900	1900	1900
		Load (kW) - 103	69	35	91	61	31
Formaldehyde	$\mu g/m^3$	9840	14700	18200	16600	19800	14600
	ppm	7.86	11.75	14.56	13.29	15.86	11.69
Acetaldehyde	$\mu g/m^3$	4060	7610	13700	5730	9680	5530
	ppm	2.22	4.15	7.46	3.12	5.30	3.02
Acetone	$\mu g/m^3$	5860	6890	15300	11600	8710	5310
	ppm	2.44	2.85	6.30	4.79	3.62	2.20
Isobutraldehyde	$\mu g/m^3$	2340	3070	2450	1410	2960	3080
+ Methyl Ethyl Ketone	ppm	0.80	1.04	0.80	0.48	0.97	1.01
Crotonaldehyde	$\mu g/m^3$	546	734	1090	252	624	2310
	ppm	0.18	0.26	0.36	0.11	0.20	0.29
Hexanaldehyde	$\mu g/m^3$	185	183	323	225	216	200
	ppm	0.04	0.04	0.09	0.05	0.05	0.05
Benzaldehyde	$\mu g/m^3$	955	1830	1860	1160	2160	2000
	ppm	0.22	0.43	0.40	0.27	0.51	0.43
Total Aldehydes	$\mu g/m^3$	23800	35000	52900	37000	44200	33000
	ppm	13.76	20.52	29.97	22.11	26.51	18.69
% Formaldehyde of Total		41%	42%	34%	45%	45%	44%

TABLE 38

Average Engine Conditions
Transient LHD Cycle

Variable	Units	Diesel		Emulsion	
		Test 1	Test 2	Test	Test 2
Engine Speed	RPM	2149	2150	2150	2150
Observed Torque	N.m	319	319	319	319
Corrected Torque	N.m	312	311	315	314
Diesel Consumption Rate	g/s	5.84	5.79	4.86	4.88
Methanol Consumption Rate	g/s	-	-	2.10	2.10
Exhaust Temperature Left	°C	321	304	315	327
Exhaust Temperature Right	°C	314	302	313	325
Combustion Air Temperature	°C	29	27	33	31
Cooling Air Temperature	°C	17	16	26	22
Oil Temperature	°C	95	94	97	96
Cylinder No. 4 Head Temp.	°C	87	81	95	92
Fuel Inlet Temperature	°C	26	25	30	29
Fuel Outlet Temperature	°C	29	27	33	32
Fuel Pressure (To Gallery)	kPa	173	174	154	155
Methanol Content	%(^{W}/w)	0	0	30	30
Diesel Energy Consumption Rate[1]	kJ/s	265	263	220	221
Methanol Energy Consumption Rate	kJ/s	0	0	48	48
Total Energy Consumption Rate	kJ/s	265	263	268	269

Notes: 1. Fuel energy based on heating values Diesel 45.36 kJ/g
Methanol 22.70 kJ/g
Cetane Improver 29.70 kJ/g

TABLE 39

Particulate Emissions - Transient LHD Cycle

Test No.	Fuel	Soluble Particulate			Insoluble Particulate			Total Particulate		
		mg/m^3	g/h	g/kW.h	mg/m^3	g/h	g/kW.h	mg/m^3	g/h	g/kW.h
1	Diesel	57.9	37.3	0.543	21.1	13.6	0.198	79.0	51.0	0.741
2	Diesel	51.1	33.0	0.480	22.5	14.5	0.211	73.6	47.5	0.691
3	Diesel	49.4	31.9	0.464	27.1	17.5	0.254	76.4	49.3	0.718
Average		52.8	34.1	0.496	23.6	15.2	0.221	76.3	49.3	0.717
4	Emulsion	46.4	30.1	0.438	9.13	5.93	0.086	55.5	36.1	0.525
5	Emulsion	48.9	31.8	0.462	9.73	6.32	0.092	58.6	38.1	0.554
6	Emulsion	48.5	31.5	0.459	8.53	5.54	0.081	57.1	37.1	0.539
Average		47.9	31.1	0.453	9.13	5.93	0.086	57.1	37.1	0.539
% Reduction in Emissions Relative to Diesel			9.3%			61%			25%	

TABLE 40

Average Gaseous Concentrations
Transient LHD Cycle

Gaseous Component	Fuel Type Diesel	Emulsion
CO_2 %	5.5	5.8
CO ppm	174	190
THC ppm[1]	115	111
NO ppm	484	369
NO_2 ppm	7	34
NO_x ppm[2]	491	403

Notes: 1. Total hydrocarbons expressed as equivalent methane.

2. Total NO_x expressed as NO and NO_2 concentrations.

TABLE 41

Average Gaseous Emission Rates

Transient LHD Cycle

Component		Fuel Type		% Change Relative To Diesel
		Diesel	Emulsion	
CO_2	g/h	65600	69700	+ 6%
	g/kW.h	945	1010	
CO	g/h	133	147	+ 11%
	g/kW.h	1.91	2.13	
THC[1]	g/h	50	49	- 2%
	g/kW.h	0.73	0.71	
NO	g/h	395	304	- 23%
	g/kW.h	5.76	4.43	
NO_2[2]	g/h	7.56	43	+ 569%
	g/kW.h	0.110	0.63	
NO_x	g/h	616	510	- 17%
	g/kW.h	8.98	7.42	

Notes: 1. Mass emissions to total hydrocarbons expressed as equivalent methane.

2. Mass emissions of NO_x expressed as NO_2.

TABLE 42

Aldehyde Concentrations

Transient LHD Cycle Testing

Carbonyl Compound		Diesel			Emulsion		
		Test 1	Test 2	Average	Test 1	Test 2	Average
Formaldehyde	μg/m^3	10800	11500	11200	4390	7940	6160
	ppm	8.63	9.21	8.92	3.52	6.36	4.94
Acetaldehyde	μg/m^3	3750	4560	4160	2600	3650	3120
	ppm	2.05	2.49	2.27	1.42	2.00	1.71
Acetone	μg/m^3	1690	6120	3905	3800	5570	4680
	ppm	0.71	2.54	1.63	1.56	2.31	1.94
Isobutraldehyde + Methyl Ethyl Ketone	μg/m^3	319	205	262	991	1140	1070
	ppm	0.09	0.09	0.09	0.31	0.40	0.36
Crotonaldehyde	μg/m^3	<162	<162	<162	<216	<216	<216
	ppm	<0.04	<0.04	<0.04	<0.08	<0.08	<0.08
Hexanaldehyde	μg/m^3	<143	<143	<143	<192	<192	<192
	ppm	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Benzaldehyde	μg/m^3	162	162	162	162	162	162
	ppm	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Total Aldehydes	μg/m^3	16600	22400	19500	11800	18300	15000
	ppm	11.48	14.33	12.91	6.81	11.07	8.95
% Formaldehyde of Total		65%	51%	57%	37%	43%	41%

TABLE 43

Unburned Methanol Emissions
Transient LHD Cycle
With Emulsion

Test No.	Volume Sampled SCM	Mass Methanol μg	Exhaust Emission Concentration $\mu g/m^3$	Methanol Emission Rate g/h
1	0.117	4.87	41.6	26.9
2	0.117	4.20	35.9	23.2
Average	0.117	4.54	38.8	25.0

TABLE 44

Crankcase
Oil Analysis - Post Testing*

Compound	Units	Maximum Acceptable Level	Analyzed Level
Aluminum	ppm	20	4
Boron			38
Chromium	ppm	8 to 10	1
Copper	ppm	<20	53
Iron	ppm	90	35
Lead	ppm	20	3
Magnesium	ppm		274
Molybdenum	ppm		1
Nickel	ppm	3	1
Silicon	ppm	12 to 15	9
Silver	ppm		1
Tin	ppm	8 to 10	2
Sodium			6
Zinc			1127
Viscosity		100 to 110	104
Sludge	%		Negligble

*Oil sample taken after 100 engine hours on oil.

TABLE 45

EQI Calculation - Input Data and Results

Test Condition	CO ppm		NO ppm		RCD $\mu g/m^3$		SO_2 ppm		NO_2 ppm		EQI		% Change in EQI with Emulsion
	Diesel	Emulsion	Diesel	Emulsion	Diesel	Emulsion	Diesel	Emulsion	Diesel	Emulsion	Diesel	Emulsion	
MTU-LHD	174	190	484	369	76.3	57.1	50	42	7	34	192	159	- 17
2300/100%[1]	302	237	651	524	59.5	30.7	85	72	37	32	200	131	- 34
2300/ 75%	173	150	647	470	44.3	34.9	68	58	11	44	150	133	- 11
2300/ 50%	156	176	494	359	69.1	54.8	51	43	20	39	184	156	- 15
2300/ 25%	126	242	347	246	86.8	107.9	37	31	26	37	206	245	+ 19
1900/100%	297	168	694	567	77.4	34.0	81	69	5	27	219	134	- 39
1900/ 75%	161	155	670	488	72.0	56.1	62	53	12	37	199	162	- 19
1900/ 50%	128	152	511	373	77.1	88.8	49	42	6	45	192	221	+ 15
1900/ 25%	131	174	341	229	69.9	87.6	34	29	5	52	165	210	+ 27

Note: 1 Speed/Percent Load

APPENDIX B

Development of the Methanol/Diesel Emulsion Fuel System Controller

ORI

Report No. 31-20014

Design of a Methanol/Diesel
Emulsion Controller
for
Diesel Engine Testing

Project: 31-20014
Work Order 14085, 15807, 15810

Submitted to: H. Vergere
Centre for Alternate Fuels Utilization
Engineering Sciences Division

Submitted by: J. Larocque
Associate Research Engineer
Microelectronics & Instrumentation
Engineering Sciences Division

February 20, 1984

RESEARCH

SHERIDAN PARK RESEARCH COMMUNITY

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SUMMARY

This report describes the design and operation of a device which controls the percentage of Methanol added to the Diesel fuel burned by a Duetz F8L413F/W, 185BHP engine, to 30% of the total fuel flow. The device measures Engine RPM and Fuel RACK position and generates the correct Voltage and current to drive the Methanol Pump Motor.

In addition to this, Engine Temperature and Methanol Pressure switch inputs are provided to inhibit the Methanol Motor appropriately.

Additional outputs are provided to drive the RACK solenoid and indicate a FAULT condition.

The correct quantity of Methanol is stored in digital form in a 8Kx8 PROM lookup table. The contents of the PROM are generated using a computer program to interpolate entered data.

1. INTRODUCTION

The controller described in this report has inputs and outputs as shown in Figure 1.

The Methanol Flow (FM) is controlled by controlling the Methanol Pump Motor Voltage (VM) as a function of Engine Speed (RPM) and RACK position (mm). The Controller is designed to provide Methanol at a rate of 30% of the total fuel flow. The control curves are stored in digital form in an 8Kx8 bit PROM lookup table.

Engine Speed is Sensed by a Kienzle Model 1,002:1 Sensor which is geared at 1/2 crank shaft speed and thereby provides 8 pulses per engine revolution.

Rack Position is Sensed by a Trans-Tek Model 244-000 LVDT (Linear Variable Differential Transformer) which provides a DC output voltage linearly related to Rack Position.

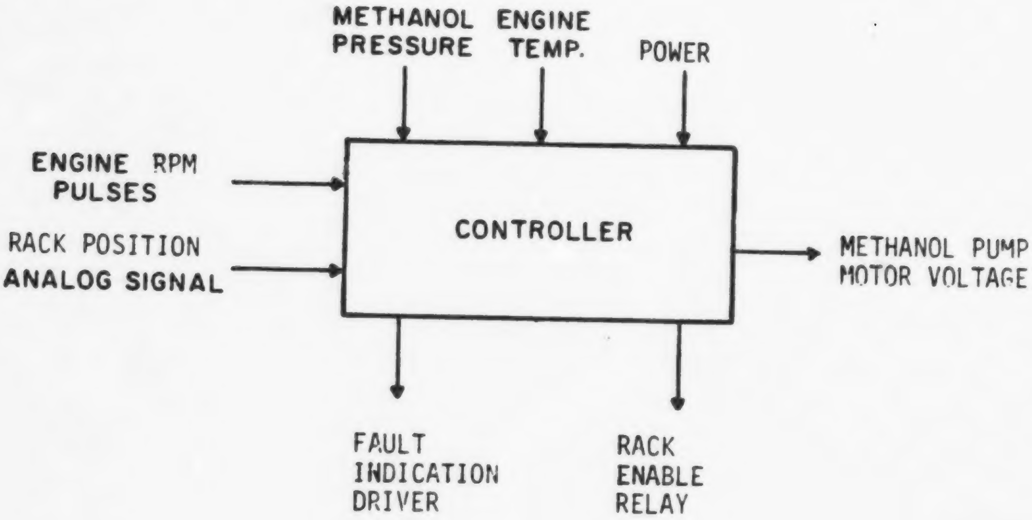
The Methanol Pump Motor is driven only when several conditions are met.

These are:
a) Engine Speed > 1250 rpm
b) Engine Load > 25% of Rated Load
c) Engine Temp > thermoswitch setpoint (TBD°C)

The Controller provides a "RACK Enable" Relay with a switch selectable delay of up to 5 minutes after Methanol pumping begins.

Failure of the Methanol Pressure to rise when the Methanol Motor is running initiates the "Restart" Cycle. The fourth unsuccessful restart attempt activates the "FAULT" output and inhibits further Methanol Motor operation.

FIGURE 1 - CONTROLLER INPUT, OUTPUT


METHANOL PRESSURE
ENGINE TEMP.
POWER
ENGINE RPM PULSES
RACK POSITION ANALOG SIGNAL
CONTROLLER
METHANOL PUMP MOTOR VOLTAGE
FAULT INDICATION DRIVER
RACK ENABLE RELAY

INPUTS

RACK POSITION: 0.07 VDC to 2.92 VDC
representing 0mm to 13.0mm RACK position
(Sensor: Trans-Tek 244-000 LVDT)

RPM: 0 Hz to 333.3 Hz @ 2.5V rms minimum representing 0 RPM to 2500 RPM
(Sensor: Kienzel 1,002:1 Speed Pickup)

ENGINE TEMP: Contact Closure if below setpoint

METHANOL PRESSURE: Contact Closure if above setpoint

POWER: +11.0 VDC to +18.0 VDC @ 0.2 to 6.5 Amps

OUTPUTS

VMOTOR: 0 Amps to 6.5 Amps @ 0.0 VDC to 10.0 VDC
(Current Limiting at approx. 6.5 Amps)

RACK ENABLE RELAY: Contact Closure to enable extended RACK travel
(20 Amps at 24 VDC)

FAULT INDICATION DRIVER: +12 VDC @ 80 mA to drive external FAULT indicator

This report is organized as follows:

Section 2 describes the Theory of Operation
Section 3 describes the method used to Generate the Lookup Table
Section 4 describes the Final Admustments required for correct Controller Operation.
Section 5 presents Conclusions and Recommendations
Appendix A presents the RAW DATA used to generate the control curves
Appendix B presents the input files and computer programs used to generate the control curves
Appendix C presents a Schematic and Parts List of the Controller

2. THEORY OF OPERATION

A block diagram of the controller is shown in Figure 2.

The controller functions basically as an electronic lookup table; that is, for each value of engine RPM and RACK position, a digital value representing the corresponding Methanol Pump Voltage is stored in a PROM. Figure 3 shows the Pump Voltage versus engine RPM and RACK position. To correctly access this electronic table, engine RPM and RACK position are converted into binary numbers and combined to form a 13 bit PROM (Programmable Read-Only Memory) address. The method used is shown in Figure 4.

The PROM stores 8,192 "words", each 8 "bits" in length. Each 8 bit digital word is converted back to an analog voltage by a Digital to Analog converter (D/A). The voltage is then amplified by the Output Circuit to the necessary voltage current level to drive the Methanol Pump Motor.

Timing and Control Circuitry ensure the proper sequencing of events to generate a correct PROM address.

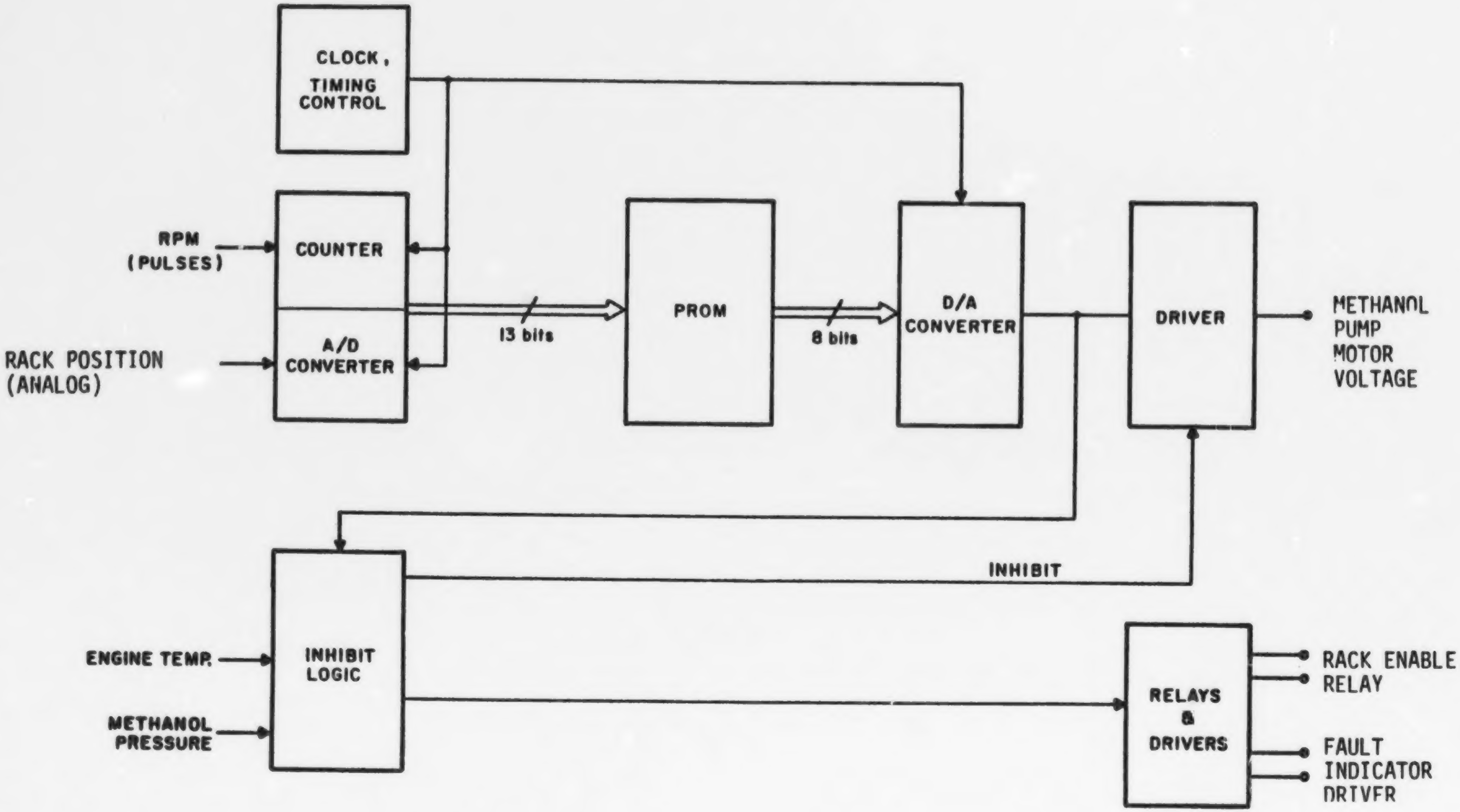
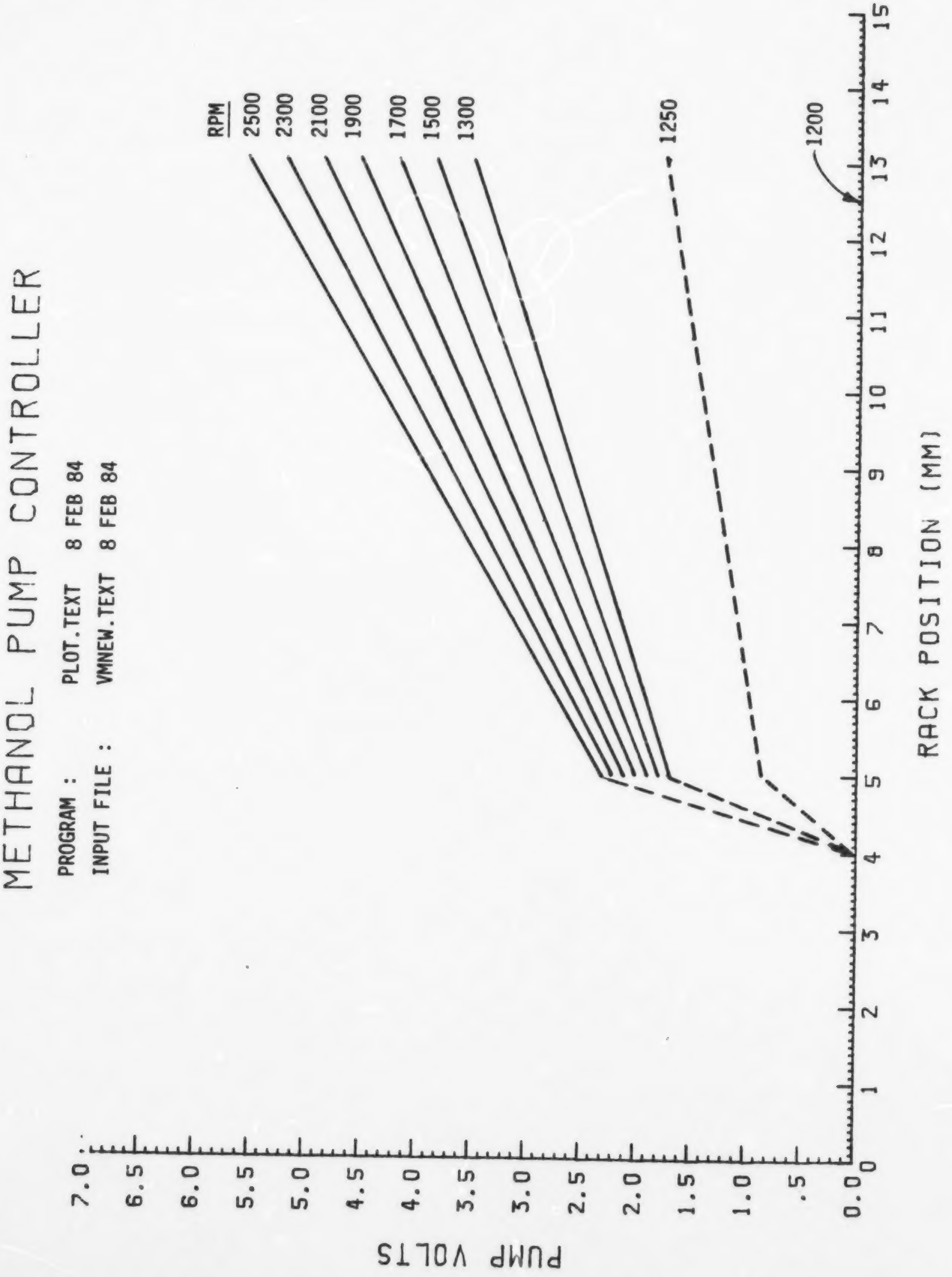
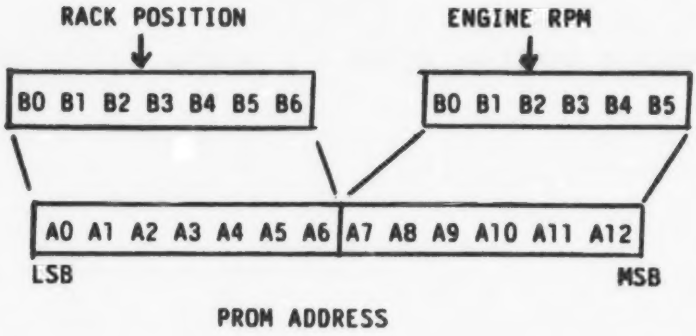

CLOCK,
TIMING
CONTROL
RPM
(PULSES)
COUNTER
RACK POSITION
(ANALOG)
A/D
CONVERTER
13 bits
PROM
8 bits
D/A
CONVERTER
DRIVER
METHANOL
PUMP
MOTOR
VOLTAGE
INHIBIT
ENGINE TEMP.
METHANOL
PRESSURE
INHIBIT
LOGIC
RELAYS
&
DRIVERS
RACK ENABLE
RELAY
FAULT
INDICATOR
DRIVER

FIG. 2 CONTROLLER BLOCK DIAGRAM.

FIGURE 3 - METHANOL PUMP CONTROLLER CHARACTERISTICS




RACK POSITION
ENGINE RPM
B0 B1 B2 B3 B4 B5 B6
B0 B1 B2 B3 B4 B5
A0 A1 A2 A3 A4 A5 A6
A7 A8 A9 A10 A11 A12
LSB
MSB
PROM ADDRESS

$$\text{RPM Resolution} = \frac{2500 \text{ rpm}}{64 \text{ bits}} = 40 \text{ rpm/bit}$$

$$\text{RACK Resolution} = \frac{13 \text{ mm}}{128 \text{ bits}} = 0.1 \text{ mm/bit}$$

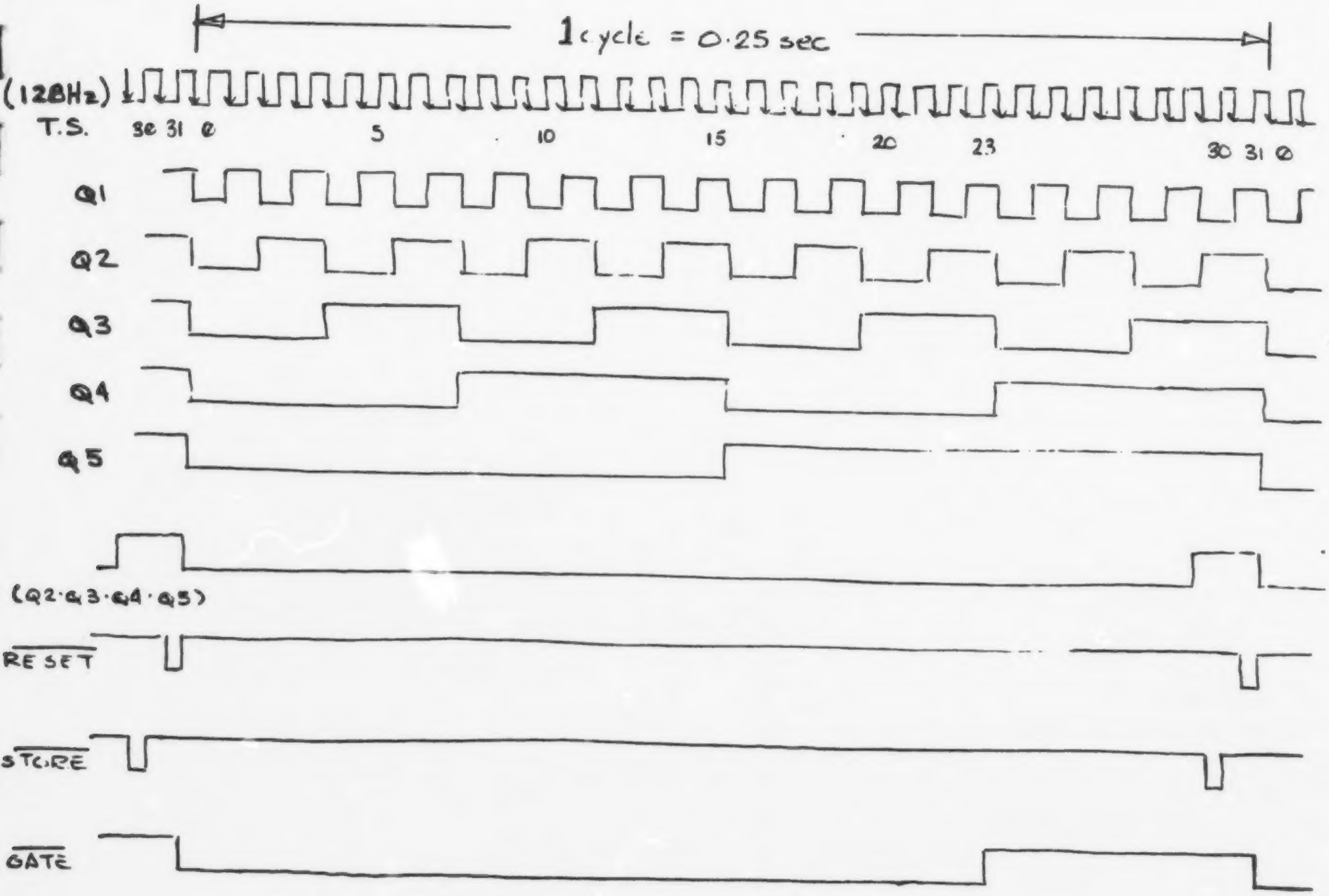
FIGURE 4 - PROM ADDRESS GENERATOR

The sequence of events shown on the Timing Diagram of Figure 5 is as follows:

Time Slot (TS) 31	- Reset RPM Counter - Start RACK A/D Conversion
TS0 to TS23	- Enable RPM Counter for 0.1875 seconds
TS24 to TS31	- Disable RPM Counter
TS30	- Enable RACK A/D Conversion READ Operation (PROM Address is now Complete) - WRITE 8-bits of data representing correct motor voltage into D/A Converter
TS31	- Reset RPM Counter - Start RACK A/D Conversion

REPEAT SEQUENCE 4 TIMES PER SECOND

FIGURE 5 - CONTROLLER TIMING DIAGRAM


1 cycle = 0.25 sec
(128Hz)
T.S.
30 31 0
5
10
15
20
23
30 31 0
Q1
Q2
Q3
Q4
Q5
(Q2·Q3·Q4·Q5)
RESET
STORE
GATE

$\overline{RESET} = \overline{Q1 \cdot (128Hz) \cdot (Q2 \cdot Q3 \cdot Q4 \cdot Q5)}$

$\overline{STORE} = \overline{\overline{Q1} \cdot (128Hz) \cdot (Q2 \cdot Q3 \cdot Q4 \cdot Q5)}$

$\overline{GATE} = \overline{Q4 \cdot Q5} = 0.1875$ sec.

In addition to this circuitry, there are several additional features:

1) Adjustable Rack Enable Delay (0-5 min)
2) Rack Solenoid Relay (24 V, 20 A)
3) Methanol Pump Fault Detect and Restart Circuitry.
4) Fault Indicator Driver (12 V, 80 mA)
5) Output Inhibit Circuit
6) Current Limiting on Output driver (6.5 A max. short cct current)

The Adjustable Rack Enable Delay allows user selectable delays of up to 5 minutes after the Methanol Pump Motor is running and the Methanol Pressure is 'ok' before the Rack Travel is increased. This feature allows the methanol percentage to increase to a nominal 30% of total fuel flow before the Rack is allowed increased travel to compensate for the energy density of Methanol which is approximately half that of Diesel fuel.

The relay driver provides Normally Open (N.O) contacts to drive the Rack Solenoid. Up to 20 A at 24 Vdc can be switched.

The Methanol Pump Fault Detect and Restart Circuitry monitors both the Methanol Pressure and the Methanol Pump Motor Voltage. A condition of no methanol pressure when the motor is provided with a voltage above its stall voltage will activate this function. (This condition may exist when the pump, which is magnetically coupled to the motor, stalls and the magnets de-couple). The circuit attempts 4 restarts, one every 2 seconds, by momentarily Inhibiting the Output Driver and hopefully allowing the pump and motor to magnetically re-couple. If no methanol pressure is detected after the 4th restart attempt, the output is permanently Inhibited and the FAULT Indicator Driver is activated. This circuit will drive an external lamp with 12 Vdc at 80 mA maximum.

The Inhibit Circuitry shuts off the Output Driver Circuit when either (or both) of two conditions exist:

1) Engine Temp below switch setpoint (i.e. engine cold)
2) No Methanol Pressure detected when Motor running (i.e. FAULT detected)

The Output Driver Circuit is designed to provide up to 6 Amperes to the Methanol Pump Motor.

In the event of a stalled motor or short circuit in the output wiring, the output transistor will attempt to deliver excessive current which may damage the controller, motor or wiring.

The output stage is protected by additional components which limit the maximum output current to approximately 6.5 Amperes. If the fault is long term, the output stage would dissipate excessive power (approx 80 watts). In this event, the controller is provided with a 5 Ampere fuse which will not be affected by normal operation but will "blow" when more than 6 Amperes are drawn for many seconds.

3. GENERATING THE LOOK-UP TABLE

The contents of the PROM lookup table are calculated by an APPLE-PASCAL program PROM.TEXT. A listing of this program and the associated input and output files are shown in Appendix B.

Figure 3 is a representative plot of the data contained in the PROM. It is generated by a second APPLE-PASCAL program, :PLOT.TEXT, whose listing is presented in Appendix B.6.

These curves were generated from Raw Data provided as follows:

1) RACK position sensor voltage versus RACK position
2) METHANOL flow rate versus MOTOR voltage
3) ENGINE CHARACTERISTICS - which relate
    a) Fuel Flow Rate ($gm.sec^{-1}$)
    b) RACK Position/Voltage
    c) Engine Load (%)
    d) Engine RPM

This RAW DATA is presented in Appendix A.

The Raw Data was plotted and expressed as linear equations:

Appendix A.1 RACK Position (mm) versus Sensor Voltage (VRACK):

$$V_{RACK} = mm \times \frac{(2.26 - 0.07)}{(21-11)} + -.07$$

$$V_{RACK} = mm \times \frac{2.19}{10} + 0.07 \text{ Volts} \qquad \text{(EQN.1)}$$

Appendix A.2 Methanol Flow (FM) versus Motor Voltage (VM)

$$FM = 1.27 \times VM - 1.79 \quad gm.sec^{-1}$$

or alternately $VM = 0.787 \times FM + 1.41$ Volts (EQN.2)

Appendix A.3 Diesel Flow (FD) versus RACK Position (mm) and Engine Speed (RPM):

$$FD = 6.169 \times 10^{-4} \times RPM \times (mm - 1.332) + 0.1762 \times mm - 2.601 \text{ gm.sec}^{-1} \qquad \text{(EQN.3)}$$

The correlation of this predictor formula (EQN.3) to the actual measured fuel flow is shown in Table 1.

RPM	% RATED LOAD			
	100	75	50	25
2300	10.21(A) 10.10(P)	7.75(A) 7.79(P)	6.01(A) 5.88(P)	4.42(A) 4.36(P)
2100	9.33(A) 9.29(P)	7.11(P) 7.23(P)	5.40(P) 5.39(P)	3.89(P) 3.84(P)
1900	8.37(A) 8.38(P)	6.26(P) 6.49(P)	4.66(P) 4.87(P)	3.40(P) 3.39(P)
1700	7.48(A) 7.39(P)	5.57(P) 5.68(P)	4.17(P) 4.27(P)	2.92(P) 2.92(P)
1500	6.68(A) 6.52(P)	4.93(P) 4.98(P)	3.77(P) 3.77(P)	2.49(P) 2.34(P)
1300	5.63(A) 5.67(P)	4.56(P) 4.55(P)	3.30(A) 3.23(P)	2.13(A) 2.15(P)

TABLE 1 - Actual (A) vs. Predicted (P) values of Fuel Flow
A: from measured raw data
P: from (EQN.3) using values of RACK Position from measured RAW DATA

EQN.3 was used to calculate the table of Fuel Flows as a function of RACK (mm) and RPM shown in Appendix B.1

The required Methanol Flow (FM) is 30% of the total flow,

i.e. $FM = 0.3 \times FD$ gm.sec^{-1} (EQN.4)

This formula was used to calculate the table of Methanol Flows shown in Appendix B.2. A final expression can be generated which combines EQNs 2,3 and 4:

$VM = 0.787 \times FM + 1.41$ Volts (EQN.2)

$$\begin{aligned} VM &= 0.787 \times (0.3 \times FD) + 1.41 \quad \text{(EQN.2 \& 4)} \\ &= 0.2361 \times FD + 1.41 \end{aligned}$$

$VM = 1.457 \times 10^{-4} \times RPM\ (mm - 1.332) + 0.0416 \times mm + 0.8$ volts

(EQNs 2,3 & 4)

This formula was used to calculate the table of Motor Voltages as a function of RACK (mm) and RPM as shown in Appendix B.3

These numbers were modified and entered into a PASCAL input file (VMNEW.TEXT, 8 FEB 84 (Appendix B.4). This input file, used in conjunction with the program - PROM.TEXT, 8 FEB 84 (Appendix B.5) generated an output file. VMOUT.TEXT, 8 FEB 84 which is then transferred to the Prolog PROM Programmer via REMOUT: to burn the final PROM.

4. FINAL ADJUSTMENTS

Several adjustments are required to ensure proper Controller operation.

These are:

1) RACK position - Gain and Offset

2) OUTPUT CIRCUIT - Gain

3) MOTOR COMPARATOR - Setpoint

The RACK position/sensor voltage relation of Appendix A.1 must be modified to match the parameters of the PROM.TEXT program of APPENDIX B.5 and also to meet the input voltage range requirements of the RACK A/D converter.

The relation is shown in Table 2.

Offset (VRsp) and Gain (VRg) adjustment

potentiometers are provided for this purpose.

RACK POSITION (mm)	POSITION SENSOR OUTPUT (VDC)	A/DINPUT (VDC)
0.0	0.07	2.50
10.0	2.26	4.42
13.0*	2.92*	5.00

*Maximum theoretical rack travel and output voltage

TABLE 2 - RACK INPUT VOLTAGE RELATION

The OUTPUT CIRCUIT gain must be adjusted to provide the voltages shown in Appendix B.3. 2500 RPM and 13 mm RACK are simulated and the output voltage adjusted to 5.59 VDC using the potentiometer provided (Vog).

The MOTOR COMPARATOR provides a signal to the Controller logic to indicate when the motor is running. The setpoint potentiometer (VMsp) is adjusted to provide a logic "HI" signal when the output voltage is above 1.6 VDC, the motor's stall voltage.

5. CONCLUSIONS AND RECOMMENDATIONS

Tests performed on the Controller in its "final" form on 9 FEB 84 demonstrated that the Methanol Flow was being controlled to 30% ± 2% of the total fuel flow over the entire range of applicable engine speeds and loads[2]. Similar performance was also observed during subsequent transient tests performed by CAFU personnel.

This performance was achieved only after three previous attempts. A primary reason for the three prior attempts is the method used to control Methanol Flow by providing a Motor Voltage. Changes in Methanol Temperature and Pump Back Pressure affected the Flow/Voltage relation greatly. The "final" version was successful primarily because the Methanol Flow and Motor Voltage was monitored at several operating points while the pump operated "in situ" on a running engine.

A major recommendation would therefore be to provide flow feed back - essentially removing the variation of pump characteristics from the performance equation.

Other recommendations concern the circuitry and these are as follows:

1) Current (versus Voltage) Feedback for the output stage would allow foldback-current limiting in the event of short circuits.

2) Output instability - caused by long wiring runs between the motor and controller should be investigated and rectified.

---

[2] 1400rpm, 40% load : $FM = 1.02$, $FD = 2.24$ $\quad \frac{FM}{FM+FD} \times 100 = 31.3\%$

2300rpm, 100% load: $DM = 3.76$, $FD = 8.22$ $\quad \frac{FM}{FM+FD} \times 100 = 31.4\%$

3) The RAW Data requires much "massaging" before it can be used by the programs. The input file should consist of "point" data, not tabular data. In most cases, the tables were generated from curves, the equations of which were estimated from given point data.

Each "point" could consist of:

(RPM, Rack Position, Fuel Flow) and therefore need not be exactly at 2300 RPM and 6.0 mm Rack for instance.

APPENDIX A : RAW DATA

A.1 RACK POSITION SENSOR

(measurements performed 30 JAN 84)

mm	VRACK
11.1	0.069
21.1	2.260
10.0	2.190

$$\text{Therefore VRACK} = (\text{mm}-11.1) \times \frac{2.26-0.07}{10} + 0.07$$

Assuming 11.1 mm is the ZERO RACK POSITION

$$\text{VRACK} = \text{mm} \times 0.219 + 0.07 \text{ VDC}$$

A.2 METHANOL PUMP VOLTAGE/FLOW

(measurements performed 8 FEB 84 with pump on running engine)

RPM	% LOAD	VMOTOR VDC	FM lb/hr	gm/s
2300	100	3.8	24	3.03
2300	100	3.9	25.2	3.18
2300	100	4.06	26.2	3.30
2300	50	2.50	11.0	1.39
2300	50	2.45	10.5	1.32
2300	50	2.45	10.1	1.27
2300	75	3.18	18.2	2.30
2300	75	3.23	18.6	2.35
2300	75	3.28	19.2	2.42

Taking VMOTOR as the "Y" variable and FM as the "X" variable and using the Linear Regression Program of the Texas Instruments TI59 Calculator:

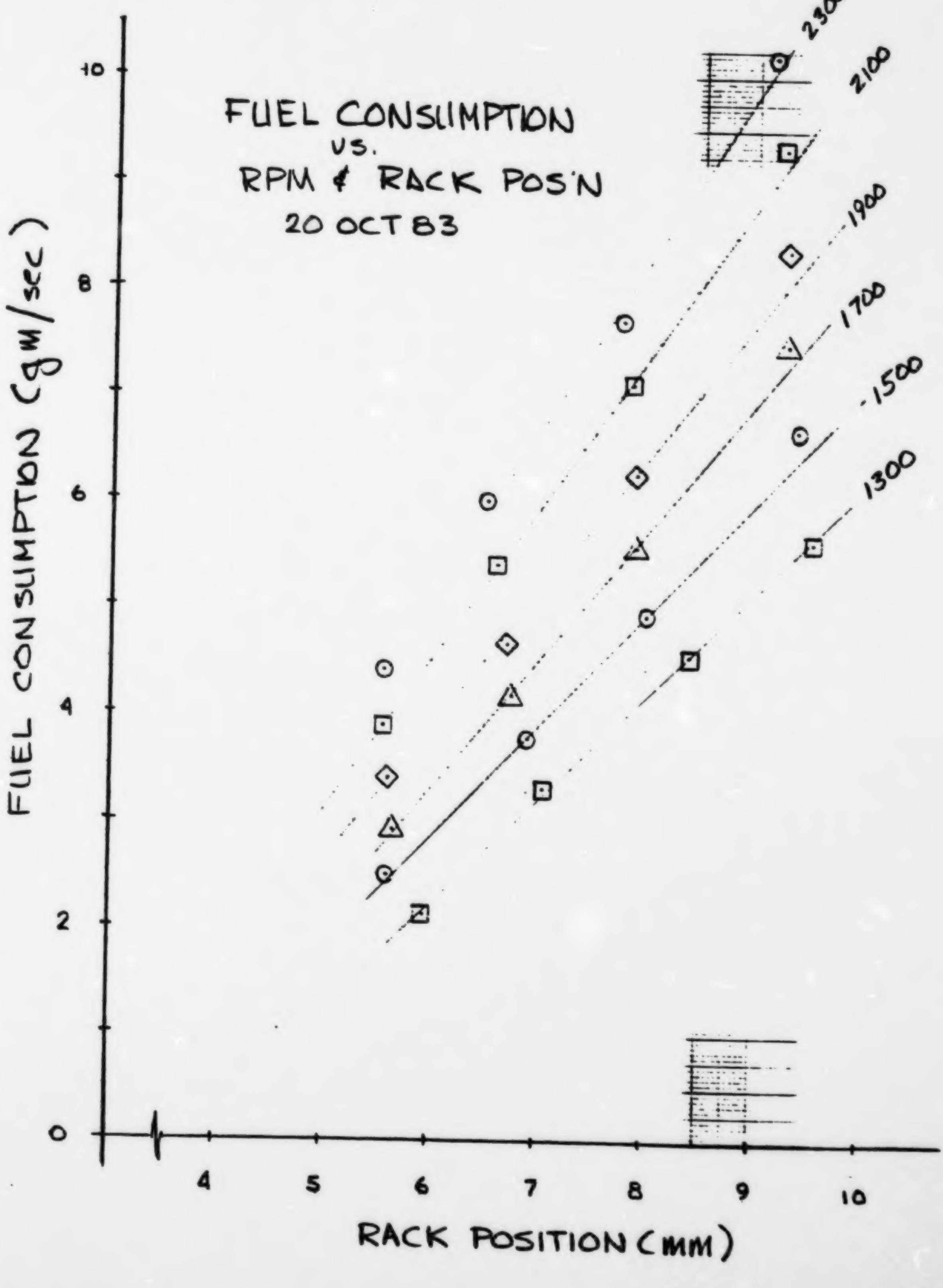
VMOTOR = 0.787 x FM + 1.41 VDC

A.3 ENGINE CHARACTERISTICS

(measurements performed 20 OCT 83 by CAFU personnel)

RPM	FUEL CONSUMPTION & RACK POSITION AT % RATED LOAD							
	100%		75%		50%		25%	
	FD (gm/s)	RACK (mm)	FD (gm/s)	RACK (mm)	FD (gm/s)	RACK (mm)	FD (gm/s)	RACK (mm)
2300	10.21	9.15	7.75	7.70	6.01	6.50	4.42	5.55
2100	9.33	9.25	7.11	7.85	5.40	6.60	3.89	5.55
1900	8.37	9.30	6.26	7.90	4.66	6.70	3.40	5.60
1700	7.48	9.30	5.57	7.90	4.17	6.75	2.92	5.65
1500	6.68	9.40	4.93	8.00	3.77	6.90	2.49	5.60
1300	5.63	9.55	4.56	8.40	3.30	7.05	2.13	5.95

Each RPM-Constant Load Line was plotted and expressed as a linear equation of the form FD = A x RACK + B using the Linear Regression Program of the Texas Instrument TI-59 Calculator.


FUEL CONSUMPTION
vs.
RPM & RACK POS'N
20 OCT 83
FUEL CONSUMPTION (gm/sec)
RACK POSITION (mm)
0
2
4
6
8
10
4
5
6
7
8
9
10
2300
2100
1900
1700
1500
1300

RPM	FD (gm/sec)
2300	FD = 1.594*RACK - 4.417
2100	FD = 1.462*RACK - 4.259
1900	FD = 1.347*RACK - 4.260
1700	FD = 1.249*RACK - 4.210
1500	FD = 1.100*RACK - 3.755
1300	FD = 0.9762*RACK - 3.579

"A" and "B" were expressed as a linear function of RPM using the same TI-59 program:

$$\text{"A"} = 6.169*10^{-4}*\text{RPM} + 0.1762$$
$$\text{"B"} = -8.217*10^{-4}*\text{RPM} - 2.601$$

Therefore, combining the equations results in an expression for fuel consumption versus RPM and RACK position:

$$\text{FD} = 6.169*10^{-4}*\text{RPM}*(\text{RACK}-1.332)+0.1762*\text{RACK}-2.601\text{gm.sec}$$

APPENDIX B : INPUT FILES AND PROGRAMS

B.1 FUEL FLOW (FD)

B.2 METHANOL FLOW (FM)

B.3 PUMP MOTOR VOLTAGE (VM)

B.4 MOTOR VOLTAGE INPUT FILE : VMNEW.TEXT

B.5 PROGRAM LISTING : PROM.TEXT

B.6 PROM OUTPUT FILE : VMOUT.TEXT

B.7 PROGRAM LISTING : PLOT.TEXT

B.8 PASCAL DISK FILE DIRECTORY - SNAFU1:

B.1 FUEL FLOW (FD):

$$FD = 6.169 * 10^{-4} * RPM(mm-1.332) + 0.1762 * mm - 2.601 gm.sec^{-1}$$

RPM RACK(MM)	0	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	2500
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	1.22	1.45	1.67	1.90	2.13	2.35	2.58	2.81	3.03	3.26	3.48	3.71	3.94
6	0	0	2.20	2.49	2.78	3.06	3.35	3.64	3.93	4.22	4.50	4.79	5.08	5.37	5.66
7	0	0	3.18	3.53	3.88	4.23	4.58	4.93	5.28	5.63	5.98	6.32	6.67	7.02	7.37
8	0	0	4.16	4.57	4.98	5.39	5.80	6.21	6.62	7.04	7.45	7.86	8.27	8.68	9.09
9	0	0	5.13	5.61	6.08	6.55	7.03	7.50	7.97	8.45	8.92	9.39	9.86	10.34	10.81
10	0	0	6.11	6.65	7.18	7.72	8.25	8.79	9.32	9.86	10.39	10.93	11.46	11.99	12.53
11	0	0	7.09	7.69	8.28	8.88	9.48	10.07	10.67	11.27	11.86	12.46	13.05	13.65	14.25
12	0	0	8.07	8.73	9.39	10.04	10.70	11.36	12.02	12.68	13.33	13.99	14.65	15.31	15.97
13	0	0	9.05	9.77	10.49	11.21	11.93	12.65	13.37	14.09	14.81	15.53	16.24	16.96	17.68

MULTIPLAN DISK - DIESEL

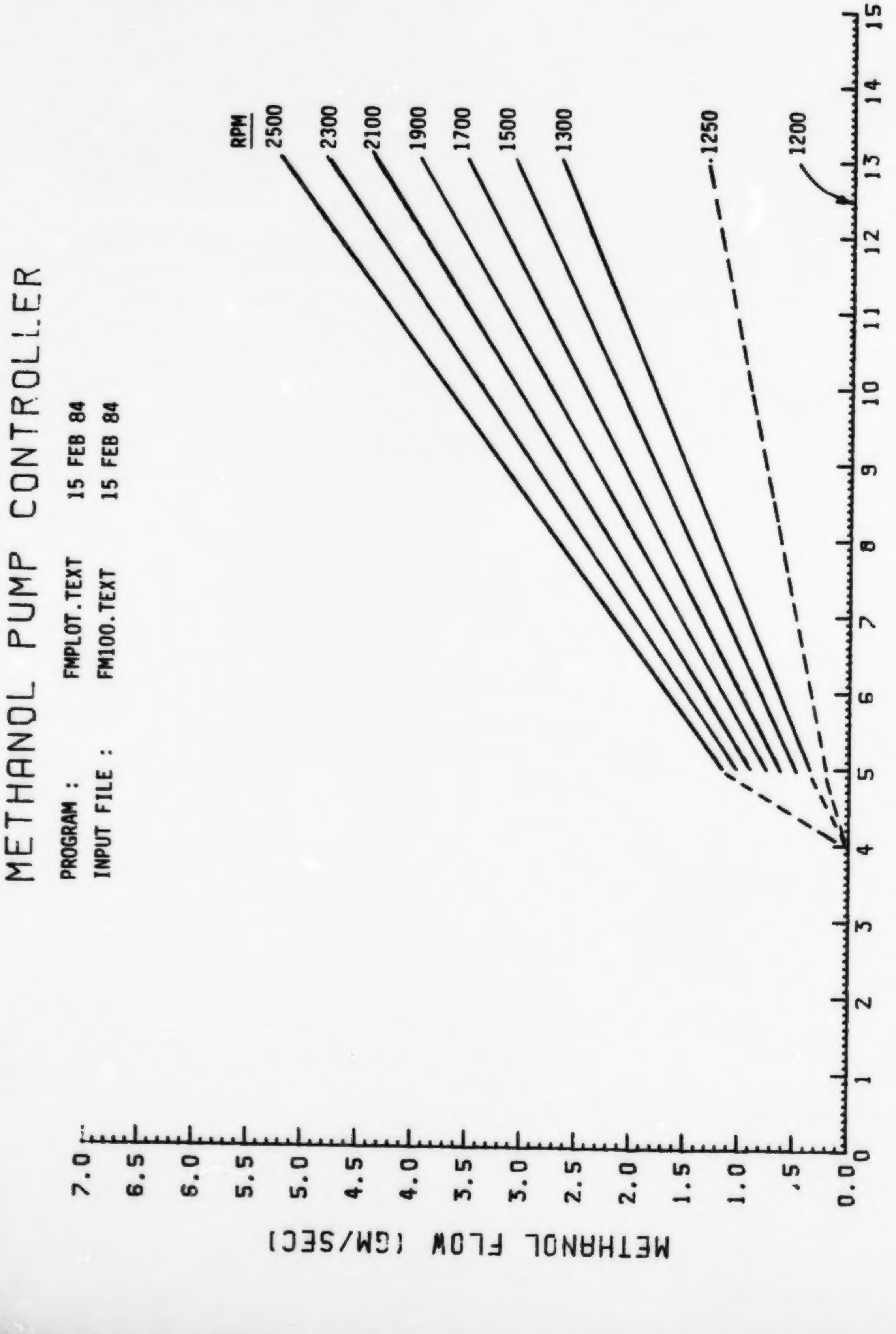
B.2 METHANOL FLOW (FM) :

$$FM = 0.3*FD$$
$$= 1.851*10^{-4}*RPM(mm-1.332)+.0527*mm-0.78 gm.sec^{-1}$$

RPM RACK (MM)	0	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	2500
0		0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0.37	0.44	0.50	0.57	0.64	0.71	0.77	0.84	0.91	0.98	1.05	1.11	1.18
6	0	0	0.66	0.75	0.83	0.92	1.01	1.09	1.18	1.27	1.35	1.44	1.52	1.61	1.70
7	0	0	0.95	1.06	1.16	1.27	1.37	1.48	1.58	1.69	1.79	1.90	2.00	2.11	2.21
8	0	0	1.25	1.37	1.49	1.62	1.74	1.86	1.99	2.11	2.23	2.36	2.48	2.60	2.73
9	0	0	1.54	1.68	1.82	1.97	2.11	2.25	2.39	2.53	2.68	2.82	2.96	3.10	3.24
10	0	0	1.83	1.99	2.16	2.32	2.48	2.64	2.80	2.96	3.12	3.28	3.44	3.60	3.76
11	0	0	2.13	2.31	2.49	2.66	2.84	3.02	3.20	3.38	3.56	3.74	3.92	4.10	4.27
12	0	0	2.42	2.62	2.82	3.01	3.21	3.41	3.61	3.80	4.00	4.20	4.40	4.59	4.79
13	0	0	2.71	2.93	3.15	3.36	3.58	3.79	4.01	4.23	4.44	4.66	4.87	5.09	5.31

MULTIPLAN DISK FILE - FMNEW

FIGURE B.2-1 METHANOL FLOW



B.3 PUMP MOTOR VOLTAGE (VM) :

$$VM = 1.457*10^{-4}*RPM*(mm-1.332)+.0416*mm+0.8VDC$$

RPM RACK (MM)	0	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	2500
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	1.70	1.75	1.81	1.86	1.91	1.97	2.02	2.07	2.13	2.18	2.23	2.29	2.34
6	0	0	1.93	2.00	2.07	2.13	2.20	2.27	2.34	2.41	2.47	2.54	2.61	2.68	2.75
7	0	0	2.16	2.24	2.33	2.41	2.49	2.57	2.66	2.74	2.82	2.90	2.99	3.07	3.15
8	0	0	2.39	2.49	2.59	2.68	2.78	2.88	2.97	3.07	3.17	3.27	3.36	3.46	3.56
9	0	0	2.62	2.73	2.85	2.96	3.07	3.18	3.29	3.40	3.52	3.63	3.74	3.85	3.96
10	0	0	2.85	2.98	3.11	3.23	3.36	3.49	3.61	3.74	3.86	3.99	4.12	4.24	4.37
11	0	0	3.08	3.23	3.37	3.51	3.65	3.79	3.93	4.07	4.21	4.35	4.49	4.63	4.78
12	0	0	3.32	3.47	3.63	3.78	3.94	4.09	4.25	4.40	4.56	4.71	4.87	5.03	5.18
13	0	0	3.55	3.72	3.89	4.06	4.23	4.40	4.57	4.74	4.91	5.08	5.25	5.42	5.59

MULTIPLAN DISK FILE - VMNEW

B.4 INPUT FILE : VMNEW.TEXT

```
RPM     0 1200 1300 1400 1500 1600 1700 1800 1900 2000 2100 2200 2300 2400 2500
RACK
0       0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
1       0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
2       0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
3       0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
4       0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
5       0    0  170  175  181  186  191  197  202  207  213  218  223  229  234
6       0    0  193  200  207  213  220  227  234  241  247  254  261  268  275
7       0    0  216  224  233  241  249  257  266  274  282  290  299  307  315
8       0    0  239  249  259  268  278  288  297  307  317  327  336  346  356
9       0    0  262  273  285  296  307  318  329  340  352  363  374  385  396
10      0    0  285  298  311  323  336  349  361  374  386  399  412  424  437
11      0    0  308  323  337  351  365  379  393  407  421  435  449  463  478
12      0    0  332  347  363  378  394  409  425  440  456  471  487  503  518
13      0    0  355  372  389  406  423  440  457  474  491  508  525  542  559
(*
VALUES OF MOTOR VOLTAGE(*100)  CALCULATED FROM :
    DIESEL = .0006169 * RPM * (R-1.332) + 0.1762R - 2.601  GM/S
    METHANOL = 0.3 * DIESEL
    VMOTOR = 0.787 * METHANOL + 1.41
           = 0.0001457 * RPM * (R-1.332) + 0.0416*R + 0.796   VOLTS


    ARRAY SIZE : ROWS = 14
                 COLS = 15
                        *)
```

PASCAL DISK FILE - SNAFU1:VMNEW.TEXT   2 FEB 84

B.5 PROGRAM LISTING : PROM.TEXT

PASCAL DISK FILES - SNAFU1:PROM.TEXT 8 FEB 84
SNAFU1:PROM.CODE 8 FEB 84

```
PROGRAM PROM;
(*SL PRINTER*)


  CONST
  PRLEN =14;
  RPMLEN =15;
  PBITLN = 127;
  RBITLN = 63;
  PVSCAL = 4.25;(* PUMP VOLTS SCALE -255 BITS/(6.0 VOLT*10) *)

  VAR INPFL,OUTFIL :TEXT;
      FILENAME:STRING[20];
      I,J,N,P,R,NUM,PRESS,TEMP : INTEGER;
      RTEMP :REAL;
      BUFFER:STRING[80];
      ASCII:  CHAR;
      PRBUF: ARRAY[1..PRLEN] OF INTEGER;
      RPMBUF: ARRAY[1..RPMLEN] OF INTEGER;
      PUMPBUF: ARRAY[1..PRLEN,1..RPMLEN] OF INTEGER;
      RPMBIT: ARRAY[1..RPMLEN] OF INTEGER;
      PRSBIT: ARRAY[1..PRLEN] OF INTEGER;
      PROMBUF: ARRAY[0..PBITLN,0..RBITLN] OF INTEGER;
      ABORT: BOOLEAN;

PROCEDURE READIN;

BEGIN

  WRITELN;
  WRITELN('METHANOL PUMP CONTROLLER PROM DATA GENERATOR');
  WRITE('TEXT FILE NAME?(A - ABORT):');
  READLN(FILENAME);            (* GET FILE NAME  *)
  IF POS('.',FILENAME) = 0 THEN FILENAME := CONCAT(FILENAME,'.TEXT');
  WRITELN(FILENAME);
  IF FILENAME[1] <> 'A' THEN
  BEGIN

    RESET (INPFL,FILENAME);

    READ(INPFL,ASCII,ASCII,ASCII);       (* THROW AWAY 'RPM'*)

    WRITELN;
    WRITELN('RPM VALUES ARE:');
    FOR I := 1 TO RPMLEN DO    (* READ RPM VALUES & SAVE*)
    BEGIN
      READ(INPFL,RPMBUF[I]);
      WRITE(RPMBUF[I],' ');
    END;

    READLN(INPFL,BUFFER);      (* CR *)

    READLN(INPFL,BUFFER);      (* THROW AWAY 'RACK'*)
```

```
      WRITELN;
      WRITELN;
      WRITELN('RACK POS''N AND METHANOL FLOW:');
      FOR J := 1 TO PRLEN DO     (* READ RACK  VALUES & SAVE *)
      BEGIN
        READ(INPFL,PRBUF[J]);
        WRITE(PRBUF[J]:2,' ');
        FOR I := 1 TO RPMLEN DO  (* FOR EACH RACK  VALUE READ ALL *)
        BEGIN                    (*   RPM VALUES AND SAVE *)
          READ(INPFL,TEMP);
          WRITE(TEMP:4,' ');
          RTEMP:= TEMP * 10;
          PUMPBUF[J,I] := ROUND(RTEMP * PVSCAL);(* SCALE VOLTS TO BITS 0 - 255*)
        END;
        READLN(INPFL,BUFFER);    (* CR *)
        WRITELN(BUFFER)
      END;
      CLOSE(INPFL)
    END
    ELSE ABORT := TRUE
  END;

  FUNCTION PSCAL (RPRESS:REAL) :INTEGER;

  VAR
    VOLPSI,OFFSET,GAINR,ADCNST,FULSCAL : REAL;

  BEGIN

  (* RACK POSITION SENSOR CONSTANTS *)

    FULSCAL := 2.92 ;               (*FULL SCALE RACK OUTPUT -VOLTS*)
    OFFSET :=  0.07 ;               (*FULL SCALE RACK OFFSET -VOLTS*)
    VOLPSI := (FULSCAL-OFFSET)/13.0; (*SLOPE - VOLTS/MM *)
    GAINR  := 2.5/FULSCAL;          (*POTENTIOMETER - VOLTS/VOLT*)
    ADCNST := 127/2.5;              (*ADC CONST - BITS/VOLT*)


   PSCAL :=  ROUND(((RPRESS * VOLPSI) +
          OFFSET) * GAINR * ADCNST)
  END;

  FUNCTION RSCAL (RRPM:REAL) :INTEGER;

  VAR
    MINSEC,PULREV,CTRINT : REAL;

  BEGIN

  (* RPM SCALE CONSTANTS *)
    MINSEC := 1/60;            (*MINUTES/SEC*)
    PULREV := 8;               (*PULSES/REV*)
    CTRINT := 0.1875;          (*COUNTER INTERVAL - SECS*)


   RSCAL := ROUND(RRPM * MINSEC * PULREV *
    CTRINT)

  END;

  (*
          SCALE
  *)
  PROCEDURE SCALE;
  RTEMP : REAL;

BEGIN

   (* CONVERT EACH INPUT RACK  VALUE TO A CORRESPONDING
        BIT VALUE OF THE ORDER 0 TO 127 *)
  WRITELN;
  WRITELN('RACK  SCALE IS (MAX.VALUE SHOULD BE (128) : ');
  FOR I := 1 TO PRLEN DO
  BEGIN
    RTEMP := PRBUF[I];
    PRSBIT[I] := PSCAL (RTEMP);
    WRITE(PRSBIT[I],' ')
  END;
  WRITELN;

   (* CONVERT EACH INPUT RPM VALUE TO A CORRESPONDING
        BIT VALUE OF THE ORDER 0 TO 63 *)
  WRITELN;
  WRITELN('RPM SCALE IS (MAX.VALUE SHOULD BE < 64) : ');
  FOR I := 1 TO RPMLEN DO
  BEGIN
    RTEMP := RPMBUF[I];
    RPMBIT[I] := RSCAL(RTEMP);
    WRITE(RPMBIT[I],' ')
  END;
  WRITELN;
  WRITELN;
  WRITE('CONTINUE?(Y/N) :');
  READ(BUFFER);
  IF BUFFER = 'N' THEN ABORT := TRUE
END;


(*
          LINT - LINEAR INTERPOLATION
*)
 PROCEDURE LINT;

  VAR
   P0,R0,A,A1,B,X,X1,Y,Y1,DX,DY : INTEGER;

  BEGIN
  WRITELN;
  WRITELN ('ZEROING PROMBUF , BE BACK IN 19 SEC');
  (* ZERO OUT PROM BUFFER*)
  FOR P := 0 TO PBITLN DO
    FOR R := 0 TO RBITLN DO
      PROMBUF[P,R] := 0;

  WRITELN;
  WRITELN('INTERPOLATING , BE BACK IN 25 SEC');

  (* GENERATE ALL RPM VALUES FOR EACH INPUT PRESSURE VALUE *)

  FOR J := 1 TO PRLEN DO
    BEGIN
    Y := PRSBIT[J];
    FOR I := 1 TO (RPMLEN-1) DO
      BEGIN
      X := RPMBIT[I];           (*    ! X   X1       *)
      X1 := RPMBIT[I+1];        (*  --------------   *)
      A := PUMPBUF[J,I];        (* Y  ! A   A1       *)
      A1 := PUMPBUF[J,I+1];     (*    !              *)
      DX := (A1-A)DIV(X1-X);    (* Y1 ! B   B1       *)
      RO := 0;
      NUM := PUMPBUF[J,I];
      FOR R := X TO X1 DO
        BEGIN
        PROMBUF[Y,R] := NUM + (DX * RO);
         RO := RO + 1
        END;
      END;
      (* FILL REMAINDER OF BUFFER WITH LAST PUMP VOLTS VALUE*)
      I := RPMBIT[RPMLEN];
      NUM := PROMBUF[Y,X1];
      WRITE(NUM,' ');
      FOR R:= I TO RBITLN DO
        PROMBUF[Y,R] := NUM;
    END;

  (* GENERATE ALL PRESSURE VALUES FOR EACH RPM VALUE *)

  WRITELN;
  FOR X := 0 TO RBITLN DO
    BEGIN
    FOR J := 1 TO (PRLEN-1) DO
      BEGIN
      Y := PRSBIT[J];
      Y1 := PRSBIT[J+1];
      A := PROMBUF[Y,X];
      B := PROMBUF[Y1,X];
      DY := (B-A)DIV(Y1-Y);

      PO := 0;
      NUM := PROMBUF[Y,X];
      FOR R := Y TO Y1 DO
        BEGIN
        PROMBUF[R,X] := NUM + (DY * PO);
         PO := PO + 1
        END;
      END;
      (* FILL REMAINDER OF BUFFER WITH LAST PUMP VOLTS VALUE*)
      I := PRSBIT[PRLEN];
      NUM := PROMBUF[Y1,X];
      WRITE (NUM,' ');
      FOR R := I TO PBITLN DO
        PROMBUF[R,X] := NUM;
    END
  END;



(*
             CONVERT DATA IN PROM BUFFER TO INTEL (HEX ASCII) FORMAT
               AND OUTPUT TO TEXTFILE
*)

PROCEDURE CONDAT;

VAR
  ASCBUF:PACKED ARRAY[1..43] OF CHAR;
  LOW,HIGH,CHKSUM,ADDRS,ADDRSI : INTEGER;
  CTEMP : CHAR;
  ZERO : BOOLEAN;

BEGIN
  WRITELN;
  WRITELN('WRITING TO OUTFIL.TEXT , BE BACK IN A MINUTE');
  FILENAME := 'OUTFIL.TEXT';
```

```
REWRITE(OUTFIL,FILENAME);
ASCBUF[1] := ':';   (* RECORD MARK *)
ASCBUF[2] := '1';   (* RECORD     *)
ASCBUF[3] := '0';   (*   LENGTH   *)
ASCBUF[8] := '0';   (* RECORD     *)
ASCBUF[9] := '0';   (*   TYPE     *)

ADDRS := 0;

FOR R := 0 TO RBITLN DO
BEGIN
  FOR P:= 0 TO PBITLN DO
  BEGIN
    I := (P MOD 16) * 2 ;
    TEMP := PROMBUF[P,R] DIV 100;
    IF TEMP <> 0 THEN ZERO := FALSE;
    NUM := TEMP DIV 16 + 48;
    IF NUM > 57 THEN NUM := NUM + 7;
    ASCBUF[I+10] := CHR(NUM);
    NUM := TEMP MOD 16 + 48;
    IF TEMP = 0 THEN NUM := 48;
    IF NUM > 57 THEN NUM := NUM + 7;
    ASCBUF[I+11] := CHR(NUM);

    IF I = 30 THEN
    BEGIN

      (* CONVERT ADDRESS TO HEXASCII *)

      ADDRSX := ADDRS;
      FOR N := 4 DOWNTO 1 DO
      BEGIN
        NUM := ADDRSX MOD 16 + 48;
        ADDRSX := ADDRSX DIV 16 ;
        IF NUM > 57 THEN NUM := NUM + 7;
        ASCBUF[3+N] := CHR(NUM)
      END;

      ADDRS := ADDRS + 16;

      (* CALCULATE & INSERT CHECKSUM IN BUFFER *)
      (* CHKSUM = TWO'S COMPLEMENT OF THE 8 BIT SUM (MODULO 256) OF
                  THE 8 BIT BYTES THAT RESULT FROM CONVERTING EACH PAIR
                  OF ASCII HEXDIGITS TO ONE BYTE OF BINARY, FROM THE
                  RECORD LENGTH FIELD TO THE LAST DATA BYTE INCLUSIVE *)

      CHKSUM := 0;
      FOR I := 2 TO 41 DO
      BEGIN
        CASE (I MOD 2) OF
        0: BEGIN
             HIGH := ORD(ASCBUF[I]) - 48 ;
             IF HIGH > 9 THEN HIGH := HIGH - 7
           END;
        1: BEGIN
             LOW := ORD(ASCBUF[I]) - 48 ;
             IF LOW > 9 THEN LOW := LOW - 7;
             NUM := (HIGH * 16) + LOW;
             CHKSUM := CHKSUM + NUM;
           END;
        END;
      END;

      TEMP := 256 - (CHKSUM MOD 256);
      TEMP := TEMP MOD 256;      (* IGNORE NO. > 256*)
```

```
        IF NUM > 57 THEN NUM := NUM + 7;
        ASCBUF[42] := CHR(NUM);
        NUM := TEMP MOD 16 + 48;
        IF NUM > 57 THEN NUM := NUM + 7;
        ASCBUF[43] := CHR(NUM);

        (* WRITE TO OUTPUT FILE *)

        IF ZERO = FALSE THEN
        BEGIN
          FOR I := 1 TO 43 DO
          BEGIN
            WRITE(OUTFIL, ASCBUF[I])
          END;
          WRITELN(OUTFIL)
        END;
        ZERO := TRUE
        END;
    END;
  END;
  WRITELN(OUTFIL,':00000001FF');
  CLOSE(OUTFIL,LOCK);
  WRITELN;
  WRITELN('FINISHED')
END;


(*
           BUILD PUMP DATA
*)
BEGIN

  ABORT := FALSE;
  READIN;       (* READ INPUT FILE *)
  IF ABORT = FALSE THEN
  BEGIN
    SCALE;        (* SCALE PRESS AND RPM AXIS *)
    IF ABORT = FALSE THEN
    BEGIN
      LINT;         (* GENERATE PUMP VOLT REFERENCE FOR ALL
                       VALUES OF PRESS & RPM*)
      CONDAT       (* CONVERT PROM BUFFER TO INTEL FORMAT & OUTPUT TO TEXT FILE *)
    END
  END
END.
```

B.6 PROM OUTPUT FILE : VMOUT.TEXT

PASCAL DISK FILE - SNAFU1:VMOUT.TEXT   8 FEB 84

```
:100FA00000000000000000000000020407090C0E11
:100FB0001013151818181919191A1A1A1B1B1B1CAB
:100FC0001C1C1D1D1D1E1E1E1F1F20202021212137
:100FD0002222222323232424242525252626262 7CE
:100FE00027272828282929292A2A2A2B2B2B2C2C69
:100FF0002D2D2D2E2E2F2F2F2F30303031313132FD
:1010200000000000000000000000040 90E13181C5E
:1010300021262B303031323333343535363737389B
:1010400039393A3B3B3C3D3D3E3F404041424243C3
:1010500044444546464748484 94A4A4B4C4D4D4E04
:101060004F4F5051525253535455555657575859 44
:101070005A5B5B5C5D5E5E5F6060616162636364 7E
:1010A00000000000000000000000070E151C242BAB
:1010B00032394048494A4B4C4D4E4F50525253548E
:1010C00055565758595A5B5C5D5E60616263646552
:1010D000666768696A6B6C6D6E6F70717273747538
:1010E0007678797A7B7C7D7D7E7F80818283858620
:1010F000878889 8A8B8D8E8F909091929394959604
:1011200000000000000000000000070E151D242B29
:10113000333A41494A4B4C4D4E50515253545556F7
:10114000575859 5A5B5C5D5E5F6061636465666 7B2
:101150006869 6A6B6C6D6E6F707172737576777893
:10116000797A7B7C7D7E7F80818283848687888973
:101170008A8B8C8D8F909192939495969798999A4B
:1011A00000000000000000000000070E161D252CA6
:1011B000343B424A4B4C4D4F50515253545556 5765
:1011C000595A5B5C5D5E5F60616263656667686912
:1011D0006A6B6C6D6E6F70717374757677787 97BEE
:1011E0007C7D7E7F8081828385868788898A8B8CBF
:1011F0008D8E909192939495969798999A9B9C9E98
:1012200000000000000000000000070F161E252D22
:10123000343C434B4C4D4E4F5152535455565859D4
:101240005A5B5C5D5E5F6061626465666768 6A6B7D
:101250006C6D6E6F70717273747576787 97A7B7C51
:101260007E7F8081828384858687898A8B8C8D8E20
:101270008F9192939495969798999B9C9D9E9FA0F1
:1012A00000000000000000000000070F161E262DA1
:1012B000353C444C4D4E4F50525354555658595A44
:1012C0005B5C5D5E5F6061626465666768 6A6B6CEB
:1012D0006D6E6F7071737475767778797B7C7D7EB7
:1012E0007F8182838485868788898A8C8D8E8F9082
:1012F000919394959697999A9B9C9D9E9FA0A1A24D
:1013200000000000000000000000070F171E262E1E
:10133000353D454C4E4F5051535455565759 5A5BB5
```

```
:101340005C5D5E5F60616264656667696A6B6C6E56
:101350006F7071727374757677797A7B7C7D7F801C
:1013600081828485868788898A8B8C8E8F909192E2
:1013700094959697999A9B9C9D9E9FA0A1A3A4A5A6
:1013A00000000000000000000000070F171F262E9D
:1013B000363E464D4F50515254555657595A5B5C24
:1013C0005D5E606162636465676869 6A6C6D6E6FBB
:1013D00071727374757677797A7B7C7D7F8081827B
:1013E000848586878 98A8B8C8D8E8F909293949535
:1013F00097989 99A9C9D9E9FA0A2A3A4A5A6A7A8F2
:1014200000000000000000000000070F171F272F1A
:10143000373F474F50515254555657595A5B5C5E8F
:101440005F60616264656667686A6B6C6E6F70711D
:101450007374757677787A7B7C7D7F8081828485D2
:1014600086878 98A8B8C8E8F90919293959697 9888
:101470009A9B9C9E9FA0A1A2A4A5A6A7A8AAABAC3C
:1014A00000000000000000000000070F171F272F9A
:1014B000373F474F5152535456575 85A5B5C5D5F04
:1014C00060616263656667686A6B6C6E6F7071738A
:1014D00074757678797A7B7C7E7F8081838485873A
:1014E00088898B8C8D8E8F9192939495979899 9BE8
:1014F0009C9D9EA0A1A2A4A5A6A7A8AAABACADAE9B
:10152000000000000000000000000810182028 3013
:10153000384048505153545557585 95B5C5D5E6074
:10154000616263656667686A6B6C6E6F70727374F4
:101550007577787 97A7C7D7E7F808283848687 88A0
:101560008A8B8C8E8F909192949596979 99A9B9D49
:101570009E9FA1A2A3A5A6A7A8AAABACADAEB0B1F1
:1015A000000000000000000000000810182028 3093
:1015B000384048515253555657595A5C5D5E5F61E9
:1015C0006263646667686 96B6C6D6F707173747663
:1015D0007778797B7C7D7E7F8182838586878 98A07
:1015E0008C8D8E909192939496979 8999B9C9D9FA9
:1015F000A0A1A3A4A6A7A8A9ABACADAEB0B1B2B34D
:10162000000000000000000000000810182029 3110
:101630003941 4A5253555657595A5C5D5E60616252
:101640006365666768 6A6B6C6E6F717273757678C6
:10165000797A7B7D7E7F818283848687898A8B8D60
:101660008E909192949596979 99A9B9C9E9FA0A2FA
:10167000A3A5A6A7A9AAABADAEAFB0B2B3B4B6B797
:1016A00000000000000000000000081019212932BD
:1016B0003A424B53555657595A5C5D5F60616364BB
:1016C0006566686 96A6B6D6E707173747577787A28
:1016D0007B7C7E7F808283848587888A8B8C8E8FBB
:1016E000919294959698999A9B9D9E9FA1A2A3A54D
:1016F000A6A8A9AAACADAFB0B1B3B4B5B6B8B9BAE3
:101720000000000000000000000008101921 2A320B
:101730003B434B5455575 85A5B5D5E606162 64652C
:10174000666769 6A6B6D6E6F717274757778 7A7B94
:101750007C7E7F808283848687888A8B8D8E909121
:10176000939496979899 9B9C9D9FA0A1A3A4A5A7AD
:10177000A8AAABADAEB0B1B2B4B5B6B8B9BABCBD3B
:1017A00000000000000000000000081119222A3388
:1017B0003B444C5556585 95B5C5D5F60626365669F
:1017C0006769 6A6B6D6E6F717274757778797B7CFF
:1017D0007E7F808283848687888A8B8D8E9091938A
:1017E000949697999A9B9C9E9FA0A2A3A4A6A7A912
:1017F000AAACADAFB0B2B3B4B6B7B9BABBBDBEBF99
:1018200000000000000000000000081119222A3307
:101830003C444D5557585A5B5D5E606163646667 12
:10184000686A6B6C6E6F7072737576787 97B7C7E6C
:101850007F808283858687898A8B8D8E90919394F1
:101860009697999A9C9D9EA0A1A2A4A5A7A8AAAB71
:10187000ADAEB0B1B3B4B5B7B8BABBBCBEBFC0C2F1
:1018A00000000000000000000000008111A222B3484
:[illegible]5E606163646667697D
```

```
:1018C000[illegible]7172747577787A7B7D7E80CE
:1018D000818384858788898B8C8E8F91929495974C
:1018E000999A9C9D9EA0A1A3A4A5A7A8A9ABADAEC3
:1018F000B0B1B3B4B6B7B9BABBBDBEC0C1C3C4C53D
:101920000000000000000000000008111A232B3402
:101930003D464F57595B5C5E5F616364666769 6AE9
:101940006B6D6E707172747577797A7C7D7F808231
:10195000838586888 98A8C8D8F9092939596989AA4
:101960009B9D9EA0A1A3A4A5A7A8AAABACAEB0B115
:10197000B3B4B6B7B9BABCBDBFC0C2C3C5C6C7C988
:1019A0000000000000000000000008111A232C35B0
:1019B0003E474F585A5C5D5F606264656768 6A6B5A
:1019C0006C6E6F717274757778 7A7B7D7F8082839D
:1019D000858688898A8C8D8F9092939596989A9B0C
:1019E0009D9EA0A2A3A4A6A7A9AAACADAEB0B2B377
:1019F000B5B6B8BABBBDBEC0C1C3C4C5C7C8CACBE3
:101A20000000000000000000000008111A232C35FF
:101A30003E4750595B5C5E606163646668696B6CCD
:101A40006D6F707273757678797B7D7E8082838509
:101A50008688898B8C8E8F909293959798 9A9B9D70
:101A60009FA0A2A3A5A6A8A9ABACADAFB0B2B4B5D8
:101A7000B7B8BABCBDBFC0C2C3C5C6C8C9CBCCCE3F
:101AA000000000000000000000009121B242D3679
:101AB0003F48515A5C5D5F606264656768 6A6B6D40
:101AC0006E707173747677797B7C7E8081838586 76
:101AD000888 98B8C8E8F9192949597989A9B9D9FD5
:101AE000A0A2A4A5A7A8A9ABACAEAFB1B2B4B6B73B
:101AF000B9BBBCBEC0C1C3C4C6C7C9CACCCDCFD09B
:101B2000000000000000000000009121B242D36FB
:101B30004049525B5D5E606263656768 6A6B6D6EAB
:101B400070717375767879 7B7C7E8082838587 88D7
:101B50008A8B8D8E909193949697999B9C9EA0A131
:101B6000A3A5A6A8A9ABACAEAFB1B2B4B5B7B9BABC
:101B7000BCBEBFC1C3C4C6C7C9CBCCCECFD1D2D4E3
:101BA000000000000000000000009121B252E3775
:101BB000404A535C5E6061636566686A6B6D6E7017
:101BC00072737576787 97B7C7E80828385878 98A3B
:101BD0008C8E8F9192949597989A9B9D9FA1A2A489
:101BE000A6A7A9ABACAEAFB1B2B4B5B7B8BABCBDDD
:101BF000BFC1C3C4C6C8C9CBCCCED0D1D3D4D6D72D
:101C2000000000000000000000009121B252E37F4
:101C3000414A535D5F606264656769 6B6C6E6F71BA
:101C4000737476777 97A7C7E7F8183858688 8A8CA7
:101C50008D8F909294959798 9A9B9D9FA1A2A4A6F0
:101C6000A7A9ABACAEB0B1B3B4B6B7B9BABCBEBF3E
:101C7000C1C3C5C6C8CACBCDCFD0D2D3D5D7D8DA89
:101CA000000000000000000000009121C252F3871
:101CB000414B545E5F616365666 86A6C6D6F7172FB
:101CC000747577787A7C7D7F8182848688898B8D14
:101CD0008F909293959798 9A9B9D9FA0A2A4A6A758
:101CE000A9ABADAEB0B1B3B5B6B8B9BBBCBEC0C29E
:101CF000C3C5C7C9CACCCECFD1D3D4D6D7D9DBDCE4
:101D2000000000000000000000009121C252F38F0
:101D3000424B555E606264656769 6B6D6E7072736D
:101D40007576787A7B7D7F80828486878 98B8D8E7D
:101D5000909193959698 9A9B9D9EA0A2A4A6A7A9C0
:101D6000ABADAFB0B2B3B5B6B8BABBBDBEC0C2C4FE
:101D7000C5C7C9CBCDCED0D2D3D5D7D8DADBDDDF3E
:101DA000000000000000000000009131C2630396C
:101DB000434C56606163656769 6A6C6E70727375D7
:101DC00076787A7B7D7F808284868789 8B8D8F90E1
:101DD0009294959799 9A9C9E9FA1A3A4A6A8AAAC19
:101DE000ADAFB1B3B4B6B8B9BBBCBEC0C1C3C5C753
:101DF000C9CACCCED0D2D3D5D7D8DADCDDDFE1E298
:101E2000000000000000000000009131B26303AE9
:101E3000444D576163646668 6A6C6E7071737576 41
```

```
:101E4000787A7B7D7F80828486878988BD8F919342
:101E5000949698999B9C9EA0A1A3A5A7A9AAACAE75
:101E6000B0B2B4B5B7B9BABCBEBFC1C3C4C6C8CAA4
:101E7000CCCED0D1D3D5D7D9DADCDEDFE1E2E4E6CF
:101EA00000000000000000000000009131D27313A67
:101EB000444E58626365676966D6F707274767784
:101EC000797B7C7E8081838587898B8C8E909294B0
:101ED0009697999B9C9EA0A1A3A5A7A8AAACAEB0DB
:101EE000B2B4B5B7B9BBBCBEC0C1C3C5C6C8CACC05
:101EF000CED0D2D4D6D7D9DBDCDEE0E1E3E5E7E82B
:101F200000000000000000000000009131D27313BE5
:101F3000454E58626466686A6C6E70717375777826
:101F40007A7C7D7F818384868886A8C8E909293951B
:101F500097999A9C9E9FA1A3A5A6A8AAACAEB0B241
:101F6000B4B5B7B9BBBCBEC0C2C3C5C7C9CACCCE65
:101F7000D0D2D4D6D8DADBDDDFE0E2E4E5E7E9EB86
:101FA00000000000000000000000009131D27313B65
:101FB000454F59636567696B6D6F70727476787998
:101FC0007B7D7F80828485878989BDBF9193959788
:101FD000989A9C9E9FA1A3A4A6A8AAACAEAFB1B3A9
:101FE000B5B7B9BBBDBEC0C2C4C5C7C9CBCCCED0C6
:101FF000D2D4D6D8DADCDDDFE1E3E4E6E8EAEBEDE3
:00000001FF
```

B.7 PROGRAM LISTING : PLOT.TEXT

PASCAL DISK FILE - SNAFU1 : PLOT.TEXT   1 FEB 84
SNAFU1 : PLOT.CODE   1 FEB 84

```
PROGRAM VMPLOT;
(*SL PRINTER*)

USES DIGIPLOT;


  CONST
  PRLEN = 14;
  RPMLEN = 15;
  PBITLN = 127;
  RBITLN = 63;

  VAR INPFL,OUTFIL :TEXT;
      FILENAME:STRING[20];
      I,J,N,P,R,NUM,PRESS,TEMP : INTEGER;
      BUFFER:STRING[80];
      ASCII:  CHAR;
      PRBUF: ARRAY[1..PRLEN] OF INTEGER;
      RPMBUF: ARRAY[1..RPMLEN] OF INTEGER;
      PUMPBUF: ARRAY[1..PRLEN,1..RPMLEN] OF INTEGER;
      RPMBIT: ARRAY[1..RPMLEN] OF INTEGER;
      PRSBIT: ARRAY[1..PRLEN] OF INTEGER;
      PROMBUF: ARRAY[0..PBITLN,0..RBITLN] OF INTEGER;
      ABORT: BOOLEAN;

PROCEDURE READIN;

BEGIN

  WRITELN;
  WRITELN('METHANOL PUMP CONTROLLER PLOTTING PROGRAM');
  WRITE('TEXT FILE NAME?(A - ABORT):');
  READLN(FILENAME);              (* GET FILE NAME  *)
  IF POS('.',FILENAME) = 0 THEN FILENAME := CONCAT(FILENAME,'.TEXT');
  WRITELN(FILENAME);
  IF FILENAME[1] <> 'A' THEN
  BEGIN

    RESET (INPFL,FILENAME);

    READ(INPFL,ASCII,ASCII,ASCII);       (* THROW AWAY 'RPM'*)

    WRITELN;
    WRITELN('RPM VALUES ARE:');
    FOR I := 1 TO RPMLEN DO     (* READ RPM VALUES & SAVE*)
    BEGIN
      READ(INPFL,RPMBUF[I]);
      WRITE(RPMBUF[I],' ');
    END;

    READLN(INPFL,BUFFER);       (* CR *)

    READLN(INPFL,BUFFER);       (* THROW AWAY 'PRESS'*)

    WRITELN;
    WRITELN;
    WRITELN('RACK POS''N AND PUMP VOLT * 100:');

    FOR J := 1 TO PRLEN DO      (* READ RACK VALUES & SAVE *)
    BEGIN
      READ(INPFL,PRBUF[J]);
      WRITE(PRBUF[J]:2,' ');
      FOR I := 1 TO RPMLEN DO   (* FOR EACH PRESS VALUE READ ALL *)
      BEGIN                     (*   RPM VALUES AND SAVE *)
        READ(INPFL,TEMP);
        WRITE(TEMP:4,' ');
        PUMPBUF[J,I] := TEMP * 10
      END;
      READLN(INPFL,BUFFER);     (* CR *)
      WRITELN(BUFFER)
    END;
    CLOSE(INPFL)
  END
  ELSE ABORT := TRUE
END;

FUNCTION PSCAL (RPRESS:REAL) :INTEGER;

VAR
  VOLPSI,OFFSET,GAINR,ADCNST,FULSCAL : REAL;

BEGIN

(* RACK POSITION SENSOR CONSTANTS *)
  FULSCAL := 2.92;                  (*FULL SCALE RACK OUTPUT -VOLTS*)
  OFFSET := 0.07;                   (* "     "     "    OFFSET -VOLTS*)
  VOLPSI := (FULSCAL-OFFSET)/13.0;  (*SLOPE - VOLTS/MM *)
  GAINR  := 2.5/FULSCAL;            (*POTENTIOMETER - VOLTS/VOLT*)
  ADCNST := 127/2.5;                (*ADC CONST - BITS/VOLT*)


PSCAL :=  ROUND(((RPRESS * VOLPSI) +
         OFFSET) * GAINR * ADCNST)
END;

FUNCTION RSCAL (RRPM:REAL) :INTEGER;

VAR
  MINSEC,PULREV,CTRINT : REAL;

BEGIN

(* RPM SCALE CONSTANTS *)
  MINSEC := 1/60;           (*MINUTES/SEC*)
  PULREV := 8;              (*PULSES/REV*)
  CTRINT := 0.1875;         (*COUNTER INTERVAL - SECS*)


RSCAL := ROUND(RRPM * MINSEC * PULREV *
 CTRINT)
```

```
END;

(*
          SCALE
*)
PROCEDURE SCALE;

VAR
  RTEMP : REAL;

BEGIN

   (* CONVERT EACH INPUT RACK VALUE TO A CORRESPONDING
        BIT VALUE OF THE ORDER 0 TO 127 *)
  WRITELN;
  WRITELN('RACK SCALE IS (MAX.VALUE SHOULD BE <128) : ');
  FOR I := 1 TO PRLEN DO
  BEGIN
    RTEMP := PRBUF[I];
    PRSBIT[I] := PSCAL (RTEMP);
    WRITE(PRSBIT[I],' ')
  END;
  WRITELN;

   (* CONVERT EACH INPUT RPM VALUE TO A CORRESPONDING
        BIT VALUE OF THE ORDER 0 TO 63 *)
  WRITELN;
  WRITELN('RPM SCALE IS (MAX.VALUE SHOULD BE < 64) : ');
  FOR I := 1 TO RPMLEN DO
  BEGIN
    RTEMP := RPMBUF[I];
    RPMBIT[I] := RSCAL(RTEMP);
    WRITE(RPMBIT[I],' ')
  END;
  WRITELN;
  WRITELN;
  WRITE('CONTINUE?(Y/N) :');
  READ(BUFFER);
  IF BUFFER = 'N' THEN ABORT := TRUE
END;


(*
          LINT - LINEAR INTERPOLATION
*)
 PROCEDURE LINT;

 VAR
   P0,R0,A,A1,B,X,X1,Y,Y1,DX,DY : INTEGER;

 BEGIN
 WRITELN;
 WRITELN ('ZEROING PROMBUF , BE BACK IN 19 SEC');
 (* ZERO OUT PROM BUFFER*)
 FOR P := 0 TO PBITLN DO
   FOR R := 0 TO RBITLN DO
     PROMBUF[P,R] := 0;

 WRITELN;
 WRITELN('INTERPOLATING , BE BACK IN 25 SEC');

 (* GENERATE ALL RPM VALUES FOR EACH INPUT PRESSURE VALUE *)

 FOR J := 1 TO PRLEN DO
   BEGIN
```

```
        Y := PRSBIT[J];
        FOR I := 1 TO (RPMLEN-1) DO
          BEGIN
          X := RPMBIT[I];            (*     ! X   X1       *)
          X1 := RPMBIT[I+1];         (*  --------------    *)
          A := PUMPBUF[J,I];         (*  Y  ! A   A1       *)
          A1 := PUMPBUF[J,I+1];      (*     !              *)
          DX := (A1-A)DIV(X1-X);     (*  Y1 ! B   B1       *)

          RO := 0;
          NUM := PUMPBUF[J,I];
          FOR R := X TO X1 DO
            BEGIN
            PROMBUF[Y,R] := NUM + (DX * RO);
            RO := RO + 1
            END;
          END
      END;

    (* GENERATE ALL RACK VALUES FOR EACH RPM VALUE *)

    FOR X := 0 TO RBITLN DO
      BEGIN
      FOR J := 1 TO (PRLEN-1) DO
        BEGIN
        Y := PRSBIT[J];
        Y1 := PRSBIT[J+1];
        A := PROMBUF[Y,X];
        B := PROMBUF[Y1,X];
        DY := (B-A)DIV(Y1-Y);

        PO := 0;
        NUM := PROMBUF[Y,X];
        FOR R := Y TO Y1 DO
          BEGIN
          PROMBUF[R,X] := NUM + (DY * PO);
          PO := PO + 1
          END;
        END
      END
   END;


(*
          PLOTPV - PLOT PUMP VOLTS
                   VERSUS RACK POS'N FOR
                   VARIOUS VALUES OF RPM.
*)

PROCEDURE PLOTPV;

VAR
  FIRST,OK,PLOTEN :BOOLEAN;
  RPMS,RPMINC,RPME :INTEGER;
  XCORD,YCORD :REAL;
  PTITL :STRING;
  XTITL :STRING;
  YTITL :STRING;

BEGIN

  PLOTEN := TRUE;
  WHILE PLOTEN = TRUE DO
  BEGIN
    WRITELN;
    WRITE('ENTER START RPM :');
    READLN(RPMS);
    OK := FALSE;
    REPEAT
      WRITELN;
      WRITE('ENTER RPM INCREMENT:');
      READLN(RPMINC);
      IF RPMINC < 500
       THEN OK := TRUE;
    UNTIL OK = TRUE;
    WRITELN;
    WRITE('ENTER END RPM :');
    READLN(RPME);

    INITDIGIPLOT(0,15,1,0,7,0.5);

    DRAWAXES;

    PTITL := 'METHANOL PUMP CONTROLLER';

    XTITL := 'RACK POSITION (MM)';

    YTITL := 'PUMP VOLTS';

    TITLES(PTITL,XTITL,YTITL);

    R := RPMS;
    WHILE R <= RPME DO
    BEGIN
      FIRST := TRUE;
      WRITELN('CHANGE PEN & PRESS RETURN');
      READLN;
      WRITELN('RPM = ',R);
      FOR P := 0 TO PRBUF[PRLEN] DO
      BEGIN
        (* GET INDICES OF PROMBF(J,I) *)
        XCORD := P;
        YCORD := R;
        J := PSCAL(XCORD);
        I := RSCAL(YCORD);
        XCORD := P;
        TEMP := PROMBUF[J,I];
        YCORD := TEMP;
        YCORD := YCORD / 1000.0;
        IF YCORD > 0 THEN
          IF FIRST = TRUE THEN
          BEGIN
            PLOTPT(XCORD,YCORD,0);
            FIRST := FALSE
          END
          ELSE PLOT(XCORD,YCORD);
      END;
      R := R + RPMINC
    END;
    HOME;
    WRITELN;
    WRITE('ANOTHER PLOT?(Y/N):');
    READLN (BUFFER);
    IF BUFFER = 'N'THEN PLOTEN := FALSE
  END;
END;


(*
           BUILD PUMP DATA
*)
```

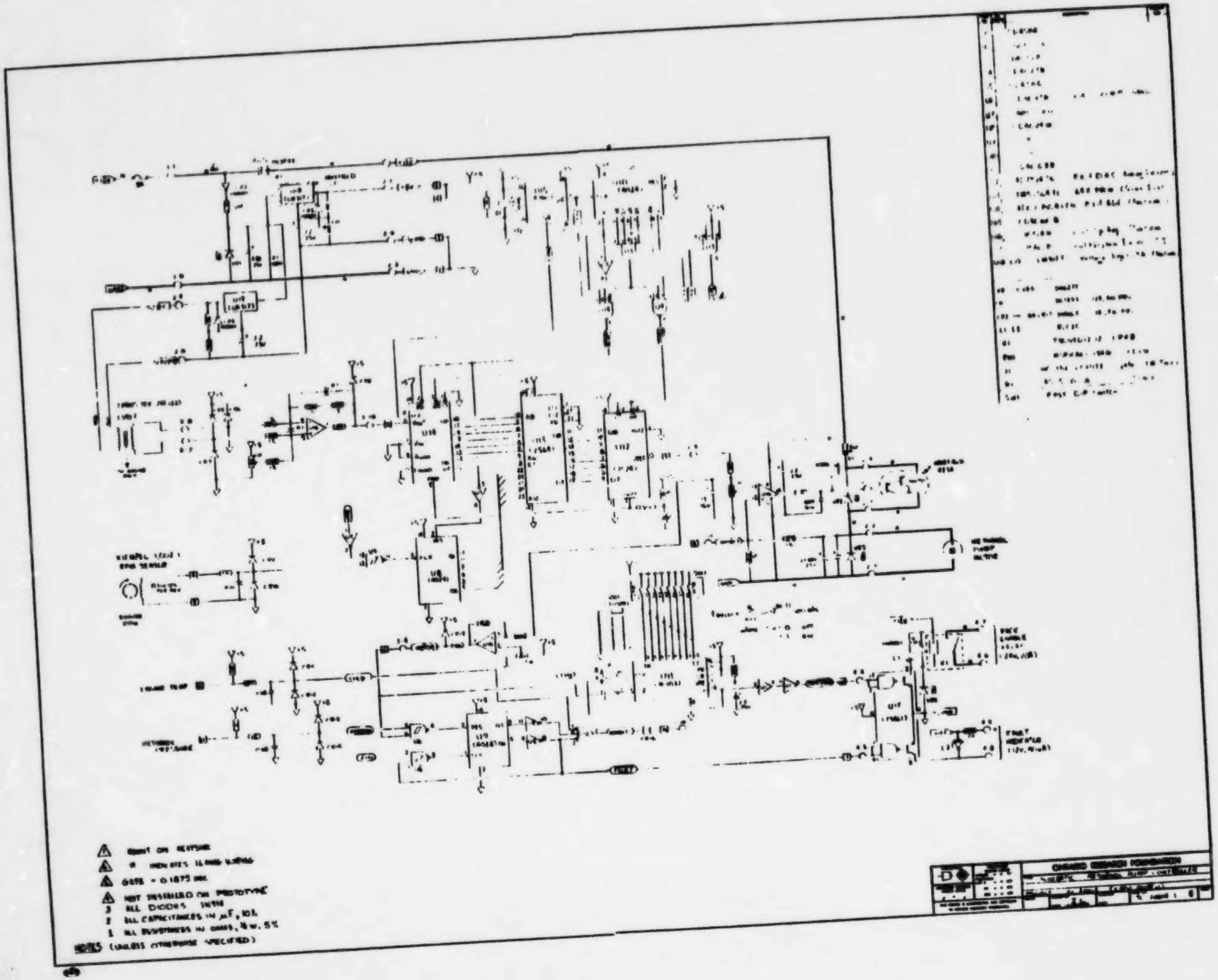
```
BEGIN

  ABORT := FALSE;
  READIN;      (* READ INPUT FILE *)
  IF ABORT = FALSE THEN
  BEGIN
    SCALE;       (* SCALE RACK  AND RPM AXIS *)
    IF ABORT = FALSE THEN
    BEGIN
      LINT;        (* GENERATE PUMP VOLT REFERENCE FOR ALL
                      VALUES OF RACK  & RPM*)
      IF ABORT = FALSE THEN
        PLOTPV;
    END
  END;
  WRITELN('FINISHED');
END.
```

B.8 PASCAL DISK FILE DIRECTORY

```
SNAFU1:
SYSTEM.COMPILER   75 19-Sep-80
SYSTEM.LINKER     24 16-Sep-80
SYSTEM.ASSMBLER   54 19-Sep-80
6500.OPCODES       2 20-Dec-78
6500.ERRORS        7 28-Mar-79
METHANOL.TEXT      6  1-Feb-84
PROM.TEXT         18  8-Feb-34
PROM.CODE          8  8-Feb-84
PLOT.TEXT         16  1-Feb-84
VMOUT.TEXT        22  8-Feb-84
VMNEW.TEXT         6  2-Feb-84
DIESEL.TEXT        6  1-Feb-84
PLOT.CODE          7  1-Feb-84
13/13 files, 23 unused, 14 in largest
```

APPENDIX C - SCHEMATIC AND PARTS LIST


NOTES (UNLESS OTHERWISE SPECIFIED)
1 ALL RESISTANCES IN OHMS, ¼ W, 5%
2 ALL CAPACITANCES IN μF, 10%
3 ALL DIODES 1N914
NOT INSTALLED ON PROTOTYPE
GATE = 0.1875
U1
U2
U9
U12
U17
U18
U19

APPENDIX C

Engine Parameter Listing for Engine Operation on Neat Diesel Over MTU-LHD Cycle

ORF - ENGINE PARAMETERS

TEST INITIALIZATION VALUES

```
REPORT REQUEST DATE            02/13/84
REPORT REQUEST TIME:           19:23:07

TEST INITIALIZATION DATE:      02/13/84
TEST INITIALIZATION TIME:      19:16:43

AVERAGING OF DATA:            150  POINTS

CELL NAME:                     CL-4
TEST ID:                       NEAT DIESEL CYCLE
TEST NAME:                     DUR 08
TEST DESCRIPTION:

ENGINE TYPE:
ENGINE MODEL:
ENGINE SERIAL NUMBER:          6283999
ENGINE DISPLACEMENT:           12.800 LITRES      781.0  CU-IN

OPERATOR NAME:

FUEL TYPE:                     NEAT
GAS OR DIESEL  :               DIESEL FUEL

AMBIENT DEWPOINT:             15.60  DEG-C        60.03  DEG-F
AMBIENT VAPOR PRESSURE:        1.77  KPA            .52  IN-HG

BAROMETRIC PRESSURE:          101.7  KPA           30.0  IN-HG
```

```
                        ORF - ENGINE TEST FACILITY                                      PAGE 2

                                  SAMPLE DATA

ENGINE TYPE                   ENGINE MODEL:                  ENGINE SERIAL NUMBER 6283999
OPERATOR NAME                      FUEL TYPE: NEAT                      CELL NAME: CL-4
-----------------------------------------------------------------------------------------------------------
TIME                   19:19:56  00:00:00  00:00:00  00:00:00  00:00:00  00:00:00  00:00:00  00:00:00  00:00:00  00:00:00
SAMPLE                       75         0         0         0         0         0         0         0         0         0
STEP                         75         0         0         0         0         0         0         0         0         0
ENGSP    RPM             2149.8        .0        .0        .0        .0        .0        .0        .0        .0        .0
ETORQ    N-M              318.7        .0        .0        .0        .0        .0        .0        .0        .0        .0
CTORQ    N-M              311.1        .0        .0        .0        .0        .0        .0        .0        .0        .0
FULFA    G/S               5.79       .00       .00       .00       .00       .00       .00       .00       .00       .00
FULFB    G/S               -.01       .00       .00       .00       .00       .00       .00       .00       .00       .00
OBSFC    G/KWH            290.6        .0        .0        .0        .0        .0        .0        .0        .0        .0

EXHTL    DEG-C            304.4        .0        .0        .0        .0        .0        .0        .0        .0        .0
EXCTL    DEG-C           1366.7        .0        .0        .0        .0        .0        .0        .0        .0        .0
EXHTR    DEG-C            302.3        .0        .0        .0        .0        .0        .0        .0        .0        .0
EXCTR    DEG-C            462.1        .0        .0        .0        .0        .0        .0        .0        .0        .0
TIARA    DEG-C             27.3        .0        .0        .0        .0        .0        .0        .0        .0        .0
TIARB    DEG-C             26.5        .0        .0        .0        .0        .0        .0        .0        .0        .0
COLAT    DEG-C             16.0        .0        .0        .0        .0        .0        .0        .0        .0        .0
OILTP    DEG-C             93.7        .0        .0        .0        .0        .0        .0        .0        .0        .0
CYLHT    DEG-C             80.7        .0        .0        .0        .0        .0        .0        .0        .0        .0
H20-O    DEG-C           -655.0        .0        .0        .0        .0        .0        .0        .0        .0        .0
FULTI    DEG-C             24.8        .0        .0        .0        .0        .0        .0        .0        .0        .0
FULTO    DEG-C             26.7        .0        .0        .0        .0        .0        .0        .0        .0        .0

EXHDP    KPA            -11.171      .000      .000      .000      .000      .000      .000      .000      .000      .000
EOILP    KPA                 .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
FUELP    KPA              174.0        .0        .0        .0        .0        .0        .0        .0        .0        .0
```

ORF - ENGINE PARAMETERS

TEST INITIALIZATION VALUES

```
REPORT REQUEST DATE:           02/13/84
REPORT REQUEST TIME:           19:25:11

TEST INITIALIZATION DATE:      02/13/84
TEST INITIALIZATION TIME:      19:16:43

AVERAGING OF DATA:             10  POINTS

CELL NAME:                     CL-4
TEST ID:                       NEAT DIESEL CYCLE
TEST NAME:                     DUR 08
TEST DESCRIPTION:

ENGINE TYPE:
ENGINE MODEL:
ENGINE SERIAL NUMBER:          6283999
ENGINE DISPLACEMENT:           12.800 LITRES      781.0  CU-IN

OPERATOR NAME:

FUEL TYPE:                     NEAT
GAS OR DIESEL   :              DIESEL FUEL

AMBIENT DEWPOINT:              15.60  DEG-C       60.03  DEG-F
AMBIENT VAPOR PRESSURE:         1.77  KPA           .52  IN-HG

BAROMETRIC PRESSURE:           101.7  KPA          30.0  IN-HG
```

```
                              ORF - ENGINE TEST FACILITY

                                     SAMPLE DATA

ENGINE  TYPE:                  ENGINE MODEL:                  ENGINE SERIAL NUMBER: 6283999
OPERATOR NAME:                   FUEL TYPE: NEAT                         CELL NAME: CL-4
----------------------------------------------------------------------------------------------------------------------
TIME                19:19:56  19:20:06  19:20:16  19:20:26  19:20:36  19:20:46  19:20:56  19:21:06  19:21:16  19:21:26
SAMPLE                     5        15        25        35        45        55        65        75        85        95
STEP                       5        15        25        35        45        55        65        75        85        95
ENGSP   RPM           2359.9    2354.4    2153.7    1366.7    1507.2    1759.9    2031.7    2327.3    2338.0    2339.6
ETORQ   N-M            232.4     211.4     287.0     444.2     334.0     547.8     374.3     347.7     346.5     328.2
CTORQ   N-M            228.4     207.7     282.4     436.7     327.5     533.8     361.4     339.2     338.1     320.2
FULFA   G/S             5.72      5.28      4.92      3.45      4.12      6.57      6.70      6.78      6.97      6.69
FULFB   G/S             -.01      -.01      -.01      -.01      -.01      -.01      -.01      -.01      -.01      -.01
OBSFC   G/KWH          358.7     364.7     273.5     195.6     281.3     234.4     302.9     288.2     295.7     299.4

EXHTL   DEG-C          276.7     296.9     285.3     268.5     239.9     286.0     319.5     343.9     341.4     330.0
EXCTL   DEG-C         1372.2    1371.3    1369.2    1371.7    1369.1    1368.2    1352.2    1368.2    1366.3    1365.3
EXHTR   DEG-C          289.2     292.5     280.8     273.4     264.9     281.1     312.7     301.0     325.1     306.6
EXCTR   DEG-C          466.4     465.0     465.6     466.4     464.0     457.2     463.3     463.0     450.0     461.0
TIARA   DEG-C           29.8      30.8      30.5      30.0      27.2      27.0      26.9      26.9      26.6      26.0
TIARB   DEG-C           29.4      29.2      29.8      29.6      28.4      25.6      21.7      26.2      26.3      26.2
COLAT   DEG-C           19.0      18.6      18.7      18.9      16.8      14.2      14.0      13.8      14.3      15.3
OILTP   DEG-C           96.5      96.1      96.4      96.7      95.1      90.2      93.1      92.5      88.6      93.6
CYLHT   DEG-C           75.9      81.4      82.1      81.5      79.2      81.2      82.1      80.8      83.0      81.1
H20-O   DEG-C         -650.2    -649.4    -649.4    -649.4    -652.5    -657.2    -657.2    -657.2    -657.2    -657.2
FULTI   DEG-C           27.1      28.2      25.5      27.9      26.0      23.9      23.0      24.1      24.3      23.7
FULTO   DEG-C           28.5      30.8      30.9      30.1      27.4      25.5      19.8      24.3      27.9      26.7

EXHDP   KPA          -11.079   -11.025   -11.186   -11.375   -10.983   -11.421   -11.089   -11.245   -11.199   -11.194
EOILP   KPA               .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
FUELP   KPA            175.9     177.3     174.9     177.8     184.4     173.3     175.4     167.3     169.4     167.4
```

ORF - ENGINE TEST FACILITY

SAMPLE DATA

NGINE TYPE: ENGINE MODEL: ENGINE SERIAL NUMBER: 6283999

PERATOR NAME: FUEL TYPE: NEAT CELL NAME: CL-4

IME		19:21:36	19:21:46	19:21:56	19:22:06	19:22:16	00:00:00	00:00:00	00:00:00	00:00:00	00:00:00
MPLE		105	115	125	135	145	0	0	0	0	0
TEP		105	115	125	135	145	0	0	0	0	0
NGSP	RPM	2330.2	2318.2	2355.3	2350.0	2354.7	0	.0	.0	.0	.0
TORQ	N-M	338.4	341.9	217.5	202.9	225.8	.0	.0	.0	.0	.0
TORQ	N-M	330.0	332.9	210.6	197.9	219.8	.0	.0	.0	.0	.0
ULFA	G/S	6.80	6.80	5.43	5.17	5.46	.00	.00	.00	.00	.00
ULFB	G/S	-.01	-.01	-.01	-.01	-.01	.00	.00	.00	.00	.00
BSFC	G/KWH	296.4	295.0	364.4	372.5	353.4	.0	.0	.0	.0	.0
XHTL	DEG-C	303.0	313.7	341.6	319.5	300.0	.0	.0	.0	.0	.0
XCTL	DEG-C	1368.1	1364.8	1361.7	1367.6	1364.1	.0	.0	.0	.0	.0
XHTR	DEG-C	334.7	335.5	335.0	315.0	287.6	.0	.0	.0	.0	.0
XCTR	DEG-C	463.2	461.2	462.6	462.8	460.0	.0	.0	.0	.0	.0
IARA	DEG-C	24.4	24.1	26.6	26.3	25.8	.0	.0	.0	.0	.0
IARB	DEG-C	25.9	25.4	22.8	26.0	25.2	.0	.0	.0	.0	.0
OLAT	DEG-C	15.3	15.6	15.7	15.3	15.2	.0	.0	.0	.0	.0
ILTP	DEG-C	93.7	92.8	93.5	93.5	93.3	.0	.0	.0	.0	.0
YLHT	DEG-C	77.1	78.4	82.1	81.2	82.9	.0	.0	.0	.0	.0
20-O	DEG-C	-657.2	-657.2	-657.2	-658.1	-658.6	.0	.0	.0	.0	.0
ULTI	DEG-C	24.1	24.7	25.0	22.4	22.6	.0	.0	.0	.0	.0
ULTO	DEG-C	25.0	26.2	23.7	26.1	27.1	.0	.0	.0	.0	.0
EXHDP	KPA	-11.241	-11.279	-11.037	-11.088	-11.118	.000	.000	.000	.000	.000
EOILP	KPA	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
FUELP	KPA	168.4	167.8	178.1	177.7	175.0	.0	.0	.0	.0	.0

```
                              ORF - ENGINE PARAMETERS                        PAGE 1

                             TEST INITIALIZATION VALUES

REPORT REQUEST DATE:           02/13/84
REPORT REQUEST TIME:           19:27:58

TEST INITIALIZATION DATE:      02/13/84
TEST INITIALIZATION TIME:      19:16:43

CELL NAME:                     CL-4
TEST ID:                       NEAT DIESEL CYCLE
TEST NAME:                     DUR 08
TEST DESCRIPTION:

ENGINE TYPE:
ENGINE MODEL:
ENGINE SERIAL NUMBER:          6283999
ENGINE DISPLACEMENT:           12.800 LITRES     781.0  CU-IN

OPERATOR NAME:

FUEL TYPE:                     NEAT
GAS OR DIESEL   :              DIESEL FUEL

AMBIENT DEWPOINT:              15.60  DEG-C       60.03  DEG-F
AMBIENT VAPOR PRESSURE:         1.77  KPA           .52  IN-HG

BAROMETRIC PRESSURE:           101.7  KPA          30.0  IN-HG
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ORF - ENGINE TEST FACILITY

SAMPLE DATA

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ENGINE TYPE:                    ENGINE MODEL:                     ENGINE SERIAL NUMBER: 6283999
OPERATOR NAME:                    FUEL TYPE: NEAT                              CELL NAME: CL-4
--------------------------------------------------------------------------------------------------------------
TIME                19:19:56  19:19:57  19:19:58  19:19:59  19:20:00  19:20:01  19:20:02  19:20:03  19:20:04  19:20:05
SAMPLE                     1         2         3         4         5         6         7         8         9        10
STEP                       1         2         3         4         5         6         7         8         9        10
ENGSP   RPM           2373.0    2380.0    2390.0    2326.0    2270.0    2313.0    2363.0    2388.0    2410.0    2386.0
ETORQ   N-M            234.0     213.8     234.7     325.0     339.9     269.7     207.7     165.9     151.0     182.1
CTORQ   N-M            227.9     210.4     231.0     319.9     334.5     265.5     204.4     163.3     148.7     178.7
FULFA   G/S             6.08      5.78      5.66      5.70      6.04      6.46      6.14      5.48      5.17      4.71
FULFB   G/S             -.00      -.00      -.00      -.00      -.01      -.01      -.00      -.01      -.01      -.00
OBSFC   G/KWH          376.3     390.6     346.9     259.3     269.1     356.0     430.3     475.8     488.1     372.7

EXHTL   DEG-C          271.4     274.5     274.5     274.5     274.5     274.5     274.5     274.5     274.5     299.5
EXCTL   DEG-C         1368.2    1372.7    1372.7    1372.7    1372.7    1372.7    1372.7    1372.7    1372.7    1372.7
EXHTR   DEG-C          289.5     288.4     288.4     288.4     288.4     288.4     288.4     288.4     288.4     294.9
EXCTR   DEG-C          463.3     466.9     466.9     466.9     466.9     466.9     466.9     466.9     466.9     465.9
TIARA   DEG-C           26.0      30.1      30.1      30.1      30.1      30.1      30.1      30.1      30.1      30.8
TIARB   DEG-C           25.5      30.0      30.0      30.0      30.0      30.0      30.0      30.0      30.0      28.8
COLAT   DEG-C           15.8      19.5      19.5      19.5      19.5      19.5      19.5      19.5      19.5      18.5
OILTP   DEG-C           93.3      96.9      96.9      96.9      96.9      96.9      96.9      96.9      96.9      96.4
CYLHT   DEG-C           72.0      75.7      75.7      75.7      75.7      75.7      75.7      75.7      75.7      81.1
H20-O   DEG-C         -657.1    -649.4    -649.4    -649.4    -649.4    -649.4    -649.4    -649.4    -649.4    -649.4
FULTI   DEG-C           23.3      27.4      27.4      27.4      27.4      27.4      27.4      27.4      27.4      28.1
FULTO   DEG-C           26.7      28.5      28.5      28.5      28.5      28.5      28.5      28.5      28.5      30.9

EXHDP   KPA          -10.934   -11.105   -11.667   -11.443   -10.759   -10.731   -10.769   -10.850   -11.016   -11.518
EOILP   KPA               .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
FUELP   KPA            172.0     171.8     164.3     163.8     187.7     180.8     185.2     183.3     177.9     172.1
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                              ORF - ENGINE TEST FACILITY                              PAGE 3

                                     SAMPLE DATA

ENGINE  TYPE:                   ENGINE MODEL:                   ENGINE SERIAL NUMBER: 6283999
OPERATOR NAME:                    FUEL TYPE: NEAT                          CELL NAME: CL-4
--------------------------------------------------------------------------------------------------
TIME                19:20:06  19:20:07  19:20:08  19:20:09  19:20:10  19:20:11  19:20:12  19:20:13  19:20:14  19:20:15
SAMPLE                    11        12        13        14        15        16        17        18        19        20
STEP                      11        12        13        14        15        16        17        18        19        20
ENGSP   RPM           2327.0    2343.0    2351.0    2390.0    2356.0    2351.0    2318.0    2366.0    2385.0    2357.0
ETORQ   N-M            236.0     254.2     227.2     191.5     178.0     192.9     212.4     211.1     203.0     207.7
CTORQ   N-M            231.7     249.5     223.1     188.0     174.7     189.3     209.0     207.6     199.7     204.3
FULFA   G/S             4.70      5.70      5.79      5.68      4.81      4.85      4.65      5.61      5.62      5.17
FULFB   G/S             -.00      -.01      -.01      -.01      -.01      -.00      -.00      -.01      -.01      -.00
OBSFC   G/KWH          294.4     329.2     372.7     427.0     394.6     367.9     338.6     386.5     399.3     363.1

EXHTL   DEG-C          299.5     299.5     299.5     299.5     299.5     299.5     293.1     293.1     293.1     293.1
EXCTL   DEG-C         1372.7    1372.7    1372.7    1372.7    1372.7    1372.7    1369.2    1369.2    1369.2    1369.2
EXHTR   DEG-C          294.9     294.9     294.9     294.9     294.9     294.9     288.9     288.9     288.9     288.9
EXCTR   DEG-C          465.9     465.9     465.9     465.9     465.9     465.9     463.7     463.7     463.7     463.7
TIARA   DEG-C           30.8      30.8      30.8      30.8      30.8      30.8      30.8      30.8      30.8      30.8
TIARB   DEG-C           28.8      28.8      28.8      28.8      28.8      28.8      29.8      29.8      29.8      29.8
COLAT   DEG-C           18.5      18.5      18.5      18.5      18.5      18.5      18.6      18.6      18.6      18.6
OILTP   DEG-C           96.4      96.4      96.4      96.4      96.4      96.4      95.7      95.7      95.7      95.7
CYLHT   DEG-C           81.1      81.1      81.1      81.1      81.1      81.1      81.8      81.8      81.8      81.8
H2O-O   DEG-C         -649.4    -649.4    -649.4    -649.4    -649.4    -649.4    -649.4    -649.4    -649.4    -649.4
FULTI   DEG-C           28.1      28.1      28.1      28.1      28.1      28.1      28.2      28.2      28.2      28.2
FULTO   DEG-C           30.9      30.9      30.9      30.9      30.9      30.9      30.7      30.7      30.7      30.7

EXHDP   KPA          -11.268   -10.983   -10.761   -10.932   -11.011   -11.179   -10.990   -10.960   -11.032   -11.130
EOILP   KPA               .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
FUELP   KPA            164.2     179.3     181.8     183.1     180.6     175.4     178.0     177.8     177.8     174.6
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                               ORF - ENGINE TEST FACILITY                                           PAGE  4

                                        SAMPLE DATA

ENGINE  TYPE:                       ENGINE MODEL:                        ENGINE SERIAL NUMBER: 6283999
OPERATOR NAME                          FUEL TYPE: NEAT                             CELL NAME: CL-4
--------------------------------------------------------------------------------------------------------------
TIME                  19:20:16  19:20:17  19:20:18  19:20:19  19:20:20  19:20:21  19:20:22  19:20:23  19:20:24  19:20:25
SAMPLE                      21        22        23        24        25        26        27        28        29        30
STEP                        21        22        23        24        25        26        27        28        29        30
ENGSF    RPM            2340.0    2339.0    2379.0    2351.0    2315.0    2107.0    2168.0    1954.0    1828.0    1756.0
ETORQ    N-M             220.5     236.0     248.1     249.5     306.8     326.4     294.7     331.8     350.0     306.1
CTORQ    N-M             216.9     232.2     244.1     245.5     301.9     321.1     290.0     326.4     344.4     301.2
FULFA    G/S              5.13      5.33      6.08      5.70      5.80      4.10      5.61      3.78      3.82      3.81
FULFB    G/S              -.01      -.00      -.01      -.01      -.00      -.00      -.01      -.01      -.01      -.00
OBSFC    G/KWH           341.5     332.1     354.3     333.9     280.8     205.2     302.0     200.6     205.1     243.6

EXHTL    DEG-C           293.1     293.1     293.1     281.9     281.9     281.9     281.9     281.9     281.9     281.9
EXCTL    DEG-C          1369.2    1369.2    1369.2    1369.2    1369.2    1369.2    1369.2    1369.2    1369.2    1369.2
EXHTR    DEG-C           288.9     288.9     288.9     277.3     277.3     277.3     277.3     277.3     277.3     277.3
EXCTR    DEG-C           463.7     463.7     463.7     466.4     466.4     466.4     466.4     466.4     466.4     466.4
TIARA    DEG-C            30.8      30.8      30.8      30.3      30.3      30.3      30.3      30.3      30.3      30.3
TIARB    DEG-C            29.8      29.8      29.8      29.9      29.9      29.9      29.9      29.9      29.9      29.9
COLAT    DEG-C            18.6      18.6      18.6      18.8      18.8      18.8      18.8      18.8      18.8      18.8
OILTP    DEG-C            95.7      95.7      95.7      96.7      96.7      96.7      96.7      96.7      96.7      96.7
CYLHT    DEG-C            81.8      81.8      81.8      82.2      82.2      82.2      82.2      82.2      82.2      82.2
H2O-O    DEG-C          -649.4    -649.4    -649.4    -649.4    -649.4    -649.4    -649.4    -649.4    -649.4    -649.4
FULTI    DEG-C            28.2      28.2      28.2      24.3      24.3      24.3      24.3      24.3      24.3      24.3
FULTO    DEG-C            30.7      30.7      30.7      30.9      30.9      30.9      30.9      30.9      30.9      30.9

EXHDP    KPA           -11.161   -11.184   -11.091   -11.450   -11.443   -10.939   -11.357   -11.401   -10.939   -10.897
EOILP    KPA                .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
FUELP    KPA             176.0     167.9     170.7     171.9     171.3     176.4     172.1     174.2     181.5     187.2
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                         ORF - ENGINE TEST FACILITY

                                SAMPLE DATA

ENGINE  TYPE:                  ENGINE MODEL:                ENGINE SERIAL NUMBER: 6283999
OPERATOR NAME                    FUEL TYPE: NEAT                   CELL NAME: CL-4
------------------------------------------------------------------------------------------------------------------
TIME                 19:20:26  19:20:27  19:20:28  19:20:29  19:20:30  19:20:31  19:20:32  19:20:33  19:20:34  19:20:35
SAMPLE                     31        32        33        34        35        36        37        38        39        40
STEP                       31        32        33        34        35        36        37        38        39        40
ENGSP   RPM            1682.0    1607.0    1470.0    1393.0    1360.0    1297.0    1270.0    1177.0    1223.0    1188.0
ETORQ   N-M             275.8     306.8     367.5     389.1     393.8     441.7     507.6     565.1     595.4     598.8
CTORQ   N-M             271.4     301.6     361.2     382.4     387.1     434.1     499.1     555.4     586.0     589.4
FULFA   G/S              3.22      3.00      3.04      3.13      3.15      3.24      3.44      3.82      4.12      4.36
FULFB   G/S              -.01      -.01      -.01      -.00      -.01      -.01      -.01      -.01      -.00      -.00
OBSFC   G/KWH           238.7     209.5     193.8     198.5     202.3     194.7     183.4     197.5     194.5     210.7

EXHTL   DEG-C           281.9     282.9     282.9     282.9     282.9     282.9     282.9     282.9     211.5     211.5
EXCTL   DEG-C          1369.2    1372.7    1372.7    1372.7    1372.7    1372.7    1372.7    1372.7    1369.8    1369.8
EXHTR   DEG-C           277.3     277.8     277.8     277.8     277.8     277.8     277.8     277.8     256.4     256.4
EXCTR   DEG-C           466.4     466.9     466.9     466.9     466.9     466.9     466.9     466.9     465.0     465.0
TIARA   DEG-C            30.3      30.7      30.7      30.7      30.7      30.7      30.7      30.7      27.4      27.4
TIARB   DEG-C            29.9      29.4      29.4      29.4      29.4      29.4      29.4      29.4      30.0      30.0
COLAT   DEG-C            18.8      19.0      19.0      19.0      19.0      19.0      19.0      19.0      18.5      18.5
OILTP   DEG-C            96.7      96.6      96.6      96.6      96.6      96.6      96.6      96.6      96.7      96.7
CYLHT   DEG-C            82.2      82.3      82.3      82.3      82.3      82.3      82.3      82.3      78.2      78.2
H2O-O   DEG-C          -649.4    -649.4    -649.4    -649.4    -649.4    -649.4    -649.4    -649.4    -649.4    -649.4
FULTI   DEG-C            24.3      28.6      28.6      28.6      28.6      28.6      28.6      28.6      27.4      27.4
FULTO   DEG-C            30.9      30.3      30.3      30.3      30.3      30.3      30.3      30.3      29.1      29.1

EXHDP   KPA           -11.270   -11.417   -11.315   -11.247   -11.352   -11.499   -11.490   -11.476   -11.457   -11.231
EOILP   KPA                .0        .0        .0        .0        .0        .0        .0        .0        .0        0
FUELP   KPA             176.5     177.2     180.2     185.2     179.9     182.9     167.4     176.2     173.8     178.8
```

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                              ORF - ENGINE TEST FACILITY

                                      SAMPLE DATA

ENGINE TYPE:                    ENGINE MODEL:                    ENGINE SERIAL NUMBER: 6283999
OPERATOR NAME:                    FUEL TYPE: NEAT                         CELL NAME: CL-4
------------------------------------------------------------------------------------------------------------
TIME                  19:20:36  19:20:37  19:20:38  19:20:39  19:20:40  19:20:41  19:20:42  19:20:43  19:20:44  19:20:45
SAMPLE                      41        42        43        44        45        46        47        48        49        50
STEP                        41        42        43        44        45        46        47        48        49        50
ENGSP    RPM            1226.0    1315.0    1419.0    1430.0    1456.0    1518.0    1585.0    1639.0    1706.0    1778.0
ETORQ    N-M             552.3     455.8     364.1     282.5     215.8     172.6     174.0     262.3     377.6     482.8
CTORQ    N-M             543.6     448.7     358.4     278.1     212.4     169.9     169.7     255.8     368.3     470.9
FULFA    G/S              4.50      4.73      4.77      3.77      3.08      2.91      3.04      3.57      4.89      5.92
FULFB    G/S              -.00      -.01      -.01      -.00      -.01      -.01      -.00      -.01      -.01      -.01
OBSFC    G/KWH           228.5     271.6     317.5     321.2     337.3     381.2     379.3     285.7     261.0     237.1

EXHTL    DEG-C           211.5     211.5     211.5     211.5     211.5     211.5     282.5     282.5     282.5     282.5
EXCTL    DEG-C          1369.8    1369.8    1369.8    1369.8    1369.8    1369.8    1368.2    1368.2    1368.2    1368.2
EXHTR    DEG-C           256.4     256.4     256.4     256.4     256.4     256.4     277.8     277.8     277.8     277.8
EXCTR    DEG-C           465.0     465.0     465.0     465.0     465.0     465.0     462.3     462.3     462.3     462.3
TIARA    DEG-C            27.4      27.4      27.4      27.4      27.4      27.4      27.0      27.0      27.0      27.0
TIARB    DEG-C            30.0      30.0      30.0      30.0      30.0      30.0      26.1      26.1      26.1      26.1
COLAT    DEG-C            18.5      18.5      18.5      18.5      18.5      18.5      14.2      14.2      14.2      14.2
OILTP    DEG-C            96.7      96.7      96.7      96.7      96.7      96.7      92.7      92.7      92.7      92.7
CYLHT    DEG-C            78.2      78.2      78.2      78.2      78.2      78.2      80.8      80.8      80.8      80.8
H2O-O    DEG-C          -649.4    -649.4    -649.4    -649.4    -649.4    -649.4    -657.2    -657.2    -657.2    -657.2
FULTI    DEG-C            27.4      27.4      27.4      27.4      27.4      27.4      23.8      23.8      23.8      23.8
FULTO    DEG-C            29.1      29.1      29.1      29.1      29.1      29.1      24.9      24.9      24.9      24.9

EXHDP    KPA           -10.789   -10.556   -10.619   -10.542   -10.526   -10.722   -11.445   -11.487   -11.525   -11.614
EOILP    KPA                .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
FUELP    KPA             187.3     194.4     191.6     196.0     200.4     185.0     180.3     170.8     166.0     172.1
```

ORF - ENGINE TEST FACILITY

SAMPLE DATA

ENGINE TYPE:
OPERATOR NAME

ENGINE MODEL:
FUEL TYPE: NEAT

ENGINE SERIAL NUMBER: 6283999
CELL NAME: CL-4

TIME		19:20:46	19:20:47	19:20:48	19:20:49	19:20:50	19:20:51	19:20:52	19:20:53	19:20:54	19:20:55
SAMPLE		51	52	53	54	55	56	57	58	59	60
STEP		51	52	53	54	55	56	57	58	59	60
ENGSP	RPM	1748.0	1791.0	1809.0	1812.0	1861.0	1901.0	1850.0	1664.0	1633.0	1530.0
ETORQ	N-M	550.9	569.1	586.0	593.4	584.6	578.6	592.7	483.5	437.6	501.7
CTORQ	N-M	537.3	555.1	571.5	577.9	569.4	563.5	577.3	470.9	426.2	488.6
FULFA	G/S	6.37	7.05	7.42	7.62	7.78	7.95	7.36	5.20	4.57	4.41
FULFB	G/S	-.01	-.01	-.01	-.01	-.01	-.01	-.01	-.01	-.00	-.01
OBSFC	G/KWH	227.6	237.9	240.6	243.6	246.0	248.6	230.7	222.2	219.9	197.5
EXHTL	DEG-C	282.5	282.5	282.5	287.6	287.6	287.6	287.6	287.6	287.6	287.6
EXCTL	DEG-C	1368.2	1368.2	1368.2	1368.2	1368.2	1368.2	1368.2	1368.2	1368.2	1368.2
EXHTR	DEG-C	277.8	277.8	277.8	282.5	282.5	282.5	282.5	282.5	282.5	282.5
EXCTR	DEG-C	462.3	462.3	462.3	455.0	455.0	455.0	455.0	455.0	455.0	455.0
TIARA	DEG-C	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0
TIARB	DEG-C	26.1	26.1	26.1	25.5	25.5	25.5	25.5	25.5	25.5	25.5
COLAT	DEG-C	14.2	14.2	14.2	14.3	14.3	14.3	14.3	14.3	14.3	14.3
OILTP	DEG-C	92.7	92.7	92.7	89.1	89.1	89.1	89.1	89.1	89.1	89.1
CYLHT	DEG-C	80.8	80.8	80.8	81.4	81.4	81.4	81.4	81.4	81.4	81.4
H20-O	DEG-C	-657.2	-657.2	-657.2	-657.2	-657.2	-657.2	-657.2	-657.2	-657.2	-657.2
FULTI	DEG-C	23.8	23.8	23.8	23.9	23.9	23.9	23.9	23.9	23.9	23.9
FULTO	DEG-C	24.9	24.9	24.9	25.7	25.7	25.7	25.7	25.7	25.7	25.7
EXHDP	KPA	-11.550	-11.525	-11.546	-11.490	-11.462	-11.562	-11.114	-10.974	-11.476	-11.513
EOILP	KPA	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
FUELP	KPA	170.0	169.1	169.4	167.9	168.4	169.3	188.3	182.4	181.5	167.1

ORF - ENGINE TEST FACILITY

SAMPLE DATA

ENGINE TYPE
OPERATOR NAME

ENGINE MODEL
FUEL TYPE: NEAT

ENGINE SERIAL NUMBER 6283999
CELL NAME CL-4

TIME		19:20:56	19:20:57	19:20:58	19:20:59	19:21:00	19:21:01	19:21:02	19:21:03	19:21:04	19:21:05
SAMPLE		61	62	63	64	65	66	67	68	69	70
STEP		61	62	63	64	65	66	67	68	69	70
ENGSP	RPM	1525.0	1528.0	1609.0	1776.0	2044.0	2313.0	2439.0	2446.0	2282.0	2355.0
ETORQ	N-M	561.7	562.4	508.4	402.6	312.2	269.0	260.3	269.7	283.2	313.6
CTORQ	N-M	540.8	541.5	489.5	387.6	300.6	259.1	250.6	259.7	276.3	305.9
FULFA	G/S	4.92	5.57	6.11	6.77	7.80	9.04	8.45	7.01	4.68	6.66
FULFB	G/S	-.01	-.01	-.01	-.01	-.00	-.01	-.01	-.00	-.00	-.01
OBSFC	G/KWH	197.4	222.7	256.7	325.7	420.0	499.2	457.8	365.3	249.2	310.2
EXHTL	DEG-C	312.5	312.5	312.5	312.5	312.5	312.5	312.5	312.5	347.1	347.1
EXCTL	DEG-C	1348.2	1348.2	1348.2	1348.2	1348.2	1348.2	1348.2	1346.2	1368.2	1368.2
EXHTR	DEG-C	312.1	312.1	312.1	312.1	312.1	312.1	312.1	312.1	315.3	315.3
EXCTR	DEG-C	463.3	463.3	463.3	463.3	463.3	463.3	463.3	463.3	463.3	463.3
TIARA	DEG-C	26.9	26.9	26.9	26.9	26.9	26.9	26.9	26.9	26.8	26.8
TIARB	DEG-C	20.6	20.6	20.6	20.6	20.6	20.6	20.6	20.6	26.2	26.2
COLAT	DEG-C	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0	13.9	13.9
OILTP	DEG-C	93.3	93.3	93.3	93.3	93.3	93.3	93.3	93.3	92.6	92.6
CYLHT	DEG-C	82.8	82.8	82.8	82.8	82.8	82.8	82.8	82.8	79.3	79.3
H2O-O	DEG-C	-657.2	-657.2	-657.2	-657.2	-657.2	-657.2	-657.2	-657.2	-657.2	-657.2
FULTI	DEG-C	22.7	22.7	22.7	22.7	22.7	22.7	22.7	22.7	23.8	23.8
FULTO	DEG-C	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9	23.2	23.2
EXHDP	KPA	-11.413	-11.107	-10.740	-10.652	-10.881	-10.993	-11.168	-11.233	-11.291	-11.413
EOILP	KPA	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
FUELP	KPA	173.3	178.1	184.3	191.1	180.1	162.7	176.0	172.5	174.1	161.5

```
                         ORF - ENGINE TEST FACILITY

                                SAMPLE DATA

ENGINE TYPE:                 ENGINE MODEL:                 ENGINE SERIAL NUMBER: 6283999
OPERATOR NAME:                 FUEL TYPE: NEAT                        CELL NAME: CL-4
-------------------------------------------------------------------------------------------------------
TIME                19:21:06  19:21:07  19:21:08  19:21:09  19:21:10  19:21:11  19:21:12  19:21:13  19:21:14  19:21:15
SAMPLE                    71        72        73        74        75        76        77        78        79        80
STEP                      71        72        73        74        75        76        77        78        79        80
ENGSP    RPM          2312.0    2302.0    2344.0    2340.0    2309.0    2352.0    2338.0    2335.0    2312.0    2329.0
ETORQ    N-M           356.0     368.2     360.8     358.7     355.4     337.2     325.0     333.1     341.9     341.2
CTORQ    N-M           347.3     359.2     351.9     350.0     346.7     328.9     317.1     325.0     333.5     332.9
FULFA    G/S            6.35      6.70      7.41      6.95      6.83      7.08      6.85      6.50      6.31      6.86
FULFB    G/S            -.01      -.01      -.01      -.01      -.00      -.01      -.01      -.00      -.01      -.01
OBSFC    G/KWH         265.1     271.7     301.3     284.8     286.1     307.0     309.9     287.4     274.7     296.9

EXHTL    DEG-C         347.1     347.1     347.1     347.1     347.1     340.7     340.7     340.7     340.7     340.7
EXCTL    DEG-C        1368.2    1368.2    1368.2    1368.2    1368.2    1368.2    1368.2    1368.2    1368.2    1368.2
EXHTR    DEG-C         315.3     315.3     315.3     315.3     315.3     286.6     286.6     286.6     286.6     286.6
EXCTR    DEG-C         463.3     463.3     463.3     463.3     463.3     462.8     462.8     462.8     462.8     462.8
TIARA    DEG-C          26.8      26.8      26.8      26.8      26.8      27.0      27.0      27.0      27.0      27.0
TIARB    DEG-C          26.2      26.2      26.2      26.2      26.2      26.2      26.2      26.2      26.2      26.2
COLAT    DEG-C          13.9      13.9      13.9      13.9      13.9      13.7      13.7      13.7      13.7      13.7
OILTP    DEG-C          92.6      92.6      92.6      92.6      92.6      92.4      92.4      92.4      92.4      92.4
CYLHT    DEG-C          79.3      79.3      79.3      79.3      79.3      82.2      82.2      82.2      82.2      82.2
H20-O    DEG-C        -657.2    -657.2    -657.2    -657.2    -657.2    -657.2    -657.2    -657.2    -657.2    -657.2
FULTI    DEG-C          23.8      23.8      23.8      23.8      23.8      24.4      24.4      24.4      24.4      24.4
FULTO    DEG-C          23.2      23.2      23.2      23.2      23.2      25.5      25.5      25.5      25.5      25.5

EXHDP    KPA         -11.392   -11.207   -11.275   -11.280   -11.123   -11.086   -11.275   -11.282   -11.235   -11.296
EOILP    KPA              .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
FUELP    KPA           169.7     162.6     165.5     167.8     170.3     167.2     170.5     168.6     170.0     160.3
```

ORF - ENGINE TEST FACILITY

SAMPLE DATA

ENGINE TYPE:
OPERATOR NAME
ENGINE MODEL:
FUEL TYPE: NEAT
ENGINE SERIAL NUMBER: 6283999
CELL NAME: CL-4

TIME		19:21:16	19:21:17	19:21:18	19:21:19	19:21:20	19:21:21	19:21:22	19:21:23	19:21:24	19:21:25
SAMPLE		81	82	83	84	85	86	87	88	89	90
STEP		81	82	83	84	85	86	87	88	89	90
ENGSP	RPM	2318.0	2301.0	2318.0	2300.0	2387.0	2337.0	2298.0	2416.0	2384.0	2321.0
ETORQ	N-M	355.4	426.8	465.9	399.9	332.4	316.9	294.0	258.9	265.7	349.3
CTORQ	N-M	346.7	416.4	454.7	390.2	324.4	309.3	286.9	252.7	259.3	340.9
FULFA	G/S	6.91	7.15	8.27	7.83	8.16	6.26	6.01	7.23	5.89	5.96
FULFB	G/S	-.01	-.01	-.01	-.01	-.01	-.01	-.01	-.01	-.01	-.00
OBSFC	G/KWH	288.4	250.1	263.4	292.6	353.8	290.8	305.9	397.3	319.6	252.9
EXHTL	DEG-C	340.7	340.7	341.6	341.6	341.6	341.6	341.6	341.6	341.6	341.6
EXCTL	DEG-C	1368.2	1368.2	1365.9	1365.9	1365.9	1365.9	1365.9	1365.9	1365.9	1365.9
EXHTR	DEG-C	286.6	286.6	334.7	334.7	334.7	334.7	334.7	334.7	334.7	334.7
EXCTR	DEG-C	462.8	462.8	446.8	446.8	446.8	446.8	446.8	446.8	446.8	446.8
TIARA	DEG-C	27.0	27.0	26.5	26.5	26.5	26.5	26.5	26.5	26.5	26.5
TIARB	DEG-C	26.2	26.2	26.3	26.3	26.3	26.3	26.3	26.3	26.3	26.3
COLAT	DEG-C	13.7	13.7	14.4	14.4	14.4	14.4	14.4	14.4	14.4	14.4
OILTP	DEG-C	92.4	92.4	87.6	87.6	87.6	87.6	87.6	87.6	87.6	87.6
CYLHT	DEG-C	82.2	82.2	83.2	83.2	83.2	83.2	83.2	83.2	83.2	83.2
H20-0	DEG-C	-657.2	-657.2	-657.2	-657.2	-657.2	-657.2	-657.2	-657.2	-657.2	-657.2
FULTI	DEG-C	24.4	24.4	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3
FULTO	DEG-C	25.5	25.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5
EXHDP	KPA	-11.504	-11.518	-11.081	-10.911	-11.086	-11.056	-10.850	-11.018	-11.609	-11.354
EOILP	KPA	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
FUELP	KPA	164.7	158.1	164.9	171.7	170.6	177.3	178.5	171.6	168.3	168.3

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                               ORF - ENGINE TEST FACILITY

                                      SAMPLE DATA

ENGINE  TYPE                     ENGINE MODEL:                      ENGINE SERIAL NUMBER: 6283999
OPERATOR NAME                       FUEL TYPE: NEAT                          CELL NAME: CL-4
------------------------------------------------------------------------------------------------------------
TIME                19:21:26  19:21:27  19:21:28  19:21:29  19:21:30  19:21:31  19:21:32  19:21:33  19:21:34  19:21:35
SAMPLE                    91        92        93        94        95        96        97        98        99       100
STEP                      91        92        93        94        95        96        97        98        99       100
ENGSF    RPM          2296.0    2405.0    2391.0    2320.0    2318.0    2319.0    2351.0    2324.0    2345.0    2327.0
ETORQ    N-M           347.9     277.1     252.2     283.2     336.5     363.5     364.1     357.4     352.0     345.9
CTORQ    N-M           339.5     270.4     246.1     276.4     330.3     354.7     355.3     348.5     343.3     337.4
FULFA    G/S            6.45      7.56      6.15      5.29      6.32      6.99      7.31      6.78      7.17      6.85
FULFB    G/S            -.00      -.01      -.01      -.01      -.00      -.01      -.00      -.00      -.01      -.01
OBSFC    G/KWH         277.8     389.8     350.9     276.8     276.9     285.1     293.6     280.9     298.6     292.5

EXHTL    DEG-C         343.0     343.0     343.0     343.0     343.0     343.0     343.0     299.6     299.6     299.6
EXCTL    DEG-C        1364.1    1364.1    1364.1    1364.1    1364.1    1364.1    1364.1    1368.1    1368.1    1368.1
EXHTR    DEG-C         295.4     295.4     295.4     295.4     295.4     295.4     295.4     332.8     332.8     332.8
EXCTR    DEG-C         460.0     460.0     460.0     460.0     460.0     460.0     460.0     463.2     463.2     463.2
TIARA    DEG-C          26.4      26.4      26.4      26.4      26.4      26.4      26.4      25.0      25.0      25.0
TIARB    DEG-C          26.3      26.3      26.3      26.3      26.3      26.3      26.3      26.0      26.0      26.0
COLAT    DEG-C          15.2      15.2      15.2      15.2      15.2      15.2      15.2      15.3      15.3      15.3
OILTP    DEG-C          93.5      93.5      93.5      93.5      93.5      93.5      93.5      93.8      93.8      93.8
CYLHT    DEG-C          83.0      83.0      83.0      83.0      83.0      83.0      83.0      76.6      76.6      76.6
H2O-O    DEG-C        -657.2    -657.2    -657.2    -657.2    -657.2    -657.2    -657.2    -657.2    -657.2    -657.2
FULTI    DEG-C          23.6      23.6      23.6      23.6      23.6      23.6      23.6      24.1      24.1      24.1
FULTO    DEG-C          27.6      27.6      27.6      27.6      27.6      27.6      27.6      24.6      24.6      24.6

EXHDP    KPA         -10.729   -10.920   -11.352   -11.347   -11.371   -11.287   -11.277   -11.200   -11.235   -11.224
EOILP    KPA              .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
FUELP    KPA           177.3     171.0     178.2     167.5     163.4     160.3     161.7     164.8     161.8     168.4
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ORF - ENGINE TEST FACILITY

SAMPLE DATA

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ENGINE  TYPE:                  ENGINE MODEL:                    ENGINE SERIAL NUMBER: 6283999
OPERATOR NAME:                    FUEL TYPE: NEAT                           CELL NAME: CL-4
-------------------------------------------------------------------------------------------------------------
TIME                19:21:36  19:21:37  19:21:38  19:21:39  19:21:40  19:21:41  19:21:42  19:21:43  19:21:44  19:21:45
SAMPLE                   101       102       103       104       105       106       107       108       109       110
STEP                     101       102       103       104       105       106       107       108       109       110
ENGSP   RPM           2330.0    2339.0    2349.0    2329.0    2287.0    2359.0    2307.0    2314.0    2327.0    2361.0
ETORQ   N-M            343.2     333.8     326.4     343.9     359.4     356.7     345.2     332.4     322.3     321.0
CTORQ   N-M            334.7     325.5     318.3     335.4     350.5     347.7     336.5     324.0     314.2     312.9
FULFA   G/S             6.80      6.86      6.92      6.54      6.46      7.42      6.56      6.72      6.87      6.82
FULFB   G/S             -.01      -.00      -.01      -.01      -.00      -.01      -.01      -.00      -.01      -.01
OBSFC   G/KWH          292.3     302.2     310.5     280.8     270.4     303.1     283.1     300.3     315.1     309.4

EXHTL   DEG-C          299.6     299.6     299.6     299.6     299.6     306.5     306.5     306.5     306.5     306.5
EXCTL   DEG-C         1368.1    1368.1    1368.1    1368.1    1368.1    1368.1    1368.1    1368.1    1368.1    1368.1
EXHTR   DEG-C          332.8     332.8     332.8     332.8     332.8     336.5     336.5     336.5     336.5     336.5
EXCTR   DEG-C          463.2     463.2     463.2     463.2     463.2     463.2     463.2     463.2     463.2     463.2
TIARA   DEG-C           25.0      25.0      25.0      25.0      25.0      23.9      23.9      23.9      23.9      23.9
TIARB   DEG-C           26.0      26.0      26.0      26.0      26.0      25.8      25.8      25.8      25.8      25.8
COLAT   DEG-C           15.3      15.3      15.3      15.3      15.3      15.3      15.3      15.3      15.3      15.3
OILTP   DEG-C           93.8      93.8      93.8      93.8      93.8      93.7      93.7      93.7      93.7      93.7
CYLHT   DEG-C           76.6      76.6      76.6      76.6      76.6      77.6      77.6      77.6      77.6      77.6
H2O-O   DEG-C         -657.2    -657.2    -657.2    -657.2    -657.2    -657.2    -657.2    -657.2    -657.2    -657.2
FULTI   DEG-C           24.1      24.1      24.1      24.1      24.1      24.1      24.1      24.1      24.1      24.1
FULTO   DEG-C           24.6      24.6      24.6      24.6      24.6      25.4      25.4      25.4      25.4      25.4

EXHDP   KPA          -11.163   -11.142   -11.338   -11.389   -11.263   -11.238   -11.177   -11.142   -11.172   -11.389
EOILP   KPA               .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
FUELP   KPA            168.9     171.1     166.9     174.7     164.8     162.6     175.0     166.9     169.3     163.9
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                               ORF - ENGINE TEST FACILITY

                                      SAMPLE DATA

ENGINE  TYPE                    ENGINE MODEL                 ENGINE SERIAL NUMBER: 6283999
OPERATOR NAME                      FUEL TYPE: NEAT                     CELL NAME: CL-4
------------------------------------------------------------------------------------------------------------
TIME                19:21:46  19:21:47  19:21:48  19:21:49  19:21:50  19:21:51  19:21:52  19:21:53  19:21:54  19:21:55
SAMPLE                   111       112       113       114       115       116       117       118       119       120
STEP                     111       112       113       114       115       116       117       118       119       120
ENGSP    RPM          2302.0    2297.0    2320.0    2319.0    2293.0    2338.0    2339.0    2311.0    2310.0    2353.0
ETORQ    N-M           344.6     362.8     358.7     352.7     352.0     340.5     329.1     337.8     334.5     306.1
CTORQ    N-M           335.9     353.6     349.8     343.8     343.2     332.0     320.8     329.4     326.1     295.2
FULFA    G/S            6.29      6.73      7.21      6.96      6.74      7.17      6.87      6.52      6.64      6.86
FULFB    G/S            -.01      -.01      -.01      -.01      -.01      -.00      -.01      -.01      -.01      -.01
OBSFC    G/KWH         272.5     277.9     298.0     292.5     287.0     309.9     307.0     287.1     295.5     327.3

EXHTL    DEG-C         306.5     306.5     311.1     311.1     311.1     311.1     311.1     311.1     311.1     346.2
EXCTL    DEG-C        1368.1    1368.1    1364.7    1364.7    1364.7    1364.7    1364.7    1364.7    1364.7    1359.0
EXHTR    DEG-C         336.5     336.5     334.7     334.7     334.7     334.7     334.7     334.7     334.7     338.8
EXCTR    DEG-C         463.2     463.2     460.5     460.5     460.5     460.5     460.5     460.5     460.5     462.3
TIARA    DEG-C          23.9      23.9      23.8      23.8      23.8      23.8      23.8      23.8      23.8      26.6
TIARB    DEG-C          25.8      25.8      25.9      25.9      25.9      25.9      25.9      25.9      25.9      21.3
COLAT    DEG-C          15.3      15.3      15.7      15.7      15.7      15.7      15.7      15.7      15.7      15.7
OILTP    DEG-C          93.7      93.7      92.5      92.5      92.5      92.5      92.5      92.5      92.5      93.4
CYLHT    DEG-C          77.6      77.6      78.0      78.0      78.0      78.0      78.0      78.0      78.0      82.4
H20-0    DEG-C        -657.2    -657.2    -657.2    -657.2    -657.2    -657.2    -657.2    -657.2    -657.2    -657.2
FULTI    DEG-C          24.1      24.1      24.9      24.9      24.9      24.9      24.9      24.9      24.9      25.1
FULTO    DEG-C          25.4      25.4      27.0      27.0      27.0      27.0      27.0      27.0      27.0      22.6

EXHDP    KPA         -11.408   -11.303   -11.305   -11.375   -11.259   -11.219   -11.361   -11.375   -11.123   -11.058
EOILP    KPA              .0        .0        .0        .0        .0        .0        .0         0        .0        .0
FUELP    KPA           168.8     163.2     170.5     168.0     165.3     165.9     168.2     166.0     166.4     175.3
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                                              SAMPLE DATA

ENGINE  TYPE:                      ENGINE MODEL:                      ENGINE SERIAL NUMBER: 6283999
OPERATOR NAME                          FUEL TYPE: NEAT                             CELL NAME: CL-4
-----------------------------------------------------------------------------------------------------------
TIME                19:21:56  19:21:57  19:21:58  19:21:59  19:22:00  19:22:01  19:22:02  19:22:03  19:22:04  19:22:05
SAMPLE                   121       122       123       124       125       126       127       128       129       130
STEP                     121       122       123       124       125       126       127       128       129       130
ENGSP   RPM           2356.0    2372.0    2360.0    2329.0    2372.0    2350.0    2377.0    2360.0    2332.0    2345.0
ETORQ   N-M            270.4     242.8     234.7     235.3     232.0     211.7     186.8     176.0     186.8     198.9
CTORQ   N-M            260.8     234.1     226.3     227.0     223.7     204.2     180.1     171.8     182.3     194.2
FULFA   G/S             6.40      5.96      5.52      5.32      5.61      5.48      5.43      4.83      4.71      5.04
FULFB   G/S             -.01      -.01      -.00      -.01      -.01      -.01      -.00      -.01      -.01      -.01
OBSFC   G/KWH          345.3     356.0     342.8     333.9     350.5     378.9     420.7     399.8     371.7     371.6

EXHTL   DEG-C          346.2     346.2     346.2     346.2     346.2     346.2     346.2     331.0     331.0     331.0
EXCTL   DEG-C         1359.0    1359.0    1359.0    1359.0    1359.0    1359.0    1359.0    1368.1    1368.1    1368.1
EXHTR   DEG-C          338.8     338.8     338.8     338.8     338.8     338.8     338.8     325.9     325.9     325.9
EXCTR   DEG-C          462.3     462.3     462.3     462.3     462.3     462.3     462.3     463.2     463.2     463.2
TIARA   DEG-C           26.6      26.6      26.6      26.6      26.6      26.6      26.6      26.6      26.6      26.6
TIARB   DEG-C           21.3      21.3      21.3      21.3      21.3      21.3      21.3      26.4      26.4      26.4
COLAT   DEG-C           15.7      15.7      15.7      15.7      15.7      15.7      15.7      15.8      15.8      15.8
OILTP   DEG-C           93.4      93.4      93.4      93.4      93.4      93.4      93.4      93.9      93.9      93.9
CYLHT   DEG-C           82.4      82.4      82.4      82.4      82.4      82.4      82.4      81.6      81.6      81.6
H20-O   DEG-C         -657.2    -657.2    -657.2    -657.2    -657.2    -657.2    -657.2    -657.2    -657.2    -657.2
FULTI   DEG-C           25.1      25.1      25.1      25.1      25.1      25.1      25.1      24.9      24.9      24.9
FULTO   DEG-C           22.6      22.6      22.6      22.6      22.6      22.6      22.6      26.4      26.4      26.4

EXHDP   KPA          -11.028   -11.051   -11.105   -11.049   -11.014   -10.927   -10.997   -11.056   -11.109   -11.039
EOILP   KPA               .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
FUELP   KPA            177.2     176.0     176.4     177.7     179.5     180.7     183.8     176.6     176.5     176.6
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                         ORF - ENGINE TEST FACILITY

                                SAMPLE DATA

ENGINE  TYPE                  ENGINE MODEL:                 ENGINE SERIAL NUMBER  6283999
OPERATOR NAME                   FUEL TYPE  NEAT                       CELL NAME:  CL-4
-----------------------------------------------------------------------------------------------------------
TIME               19:22:06  19:22:07  19:22:08  19:22:09  19:22:10  19:22:11  19:22:12  19:22:13  19:22:14  19:22:15
SAMPLE                  131       132       133       134       135       136       137       138       139       140
STEP                    131       132       133       134       135       136       137       138       139       140
ENGSP   RPM          2359.0    2391.0    2378.0    2285.0    2357.0    2354.0    2355.0    2357.0    2335.0    2329.0
ETORQ   N-M           196.2     190.2     200.9     219.8     223.9     210.4     192.9     188.1     196.9     209.7
CTORQ   N-M           191.5     185.6     196.1     214.6     218.2     205.0     187.9     183.3     191.9     204.4
FULFA   G/S            5.30      5.39      5.00      4.48      5.72      5.43      5.28      5.03      4.90      5.13
FULFB   G/S            -.00      -.00      -.01      -.01      -.00      -.00      -.01      -.01      -.01      -.00
OBSFC   G/KWH         393.8     407.9     359.6     306.8     372.8     376.8     399.5     389.9     366.7     361.3

EXHTL   DEG-C         331.0     331.0     331.0     331.0     311.9     311.9     311.9     311.9     311.9     311.9
EXCTL   DEG-C        1368.1    1368.1    1368.1    1368.1    1367.3    1367.3    1367.3    1367.3    1367.3    1367.3
EXHTR   DEG-C         325.9     325.9     325.9     325.9     307.7     307.7     307.7     307.7     307.7     307.7
EXCTR   DEG-C         463.2     463.2     463.2     463.2     462.6     462.6     462.6     462.6     462.6     462.6
TIARA   DEG-C          26.6      26.6      26.6      26.6      26.1      26.1      26.1      26.1      26.1      26.1
TIARB   DEG-C          26.4      26.4      26.4      26.4      25.7      25.7      25.7      25.7      25.7      25.7
COLAT   DEG-C          15.8      15.8      15.8      15.8      14.9      14.9      14.9      14.9      14.9      14.9
OILTP   DEG-C          93.9      93.9      93.9      93.9      93.3      93.3      93.3      93.3      93.3      93.3
CYLHT   DEG-C          81.6      81.6      81.6      81.6      81.0      81.0      81.0      81.0      81.0      81.0
H2O-O   DEG-C        -657.2    -657.2    -657.2    -657.2    -658.6    -658.6    -658.6    -658.6    -658.6    -658.6
FULTI   DEG-C          24.9      24.9      24.9      24.9      20.7      20.7      20.7      20.7      20.7      20.7
FULTO   DEG-C          26.4      26.4      26.4      26.4      25.8      25.8      25.8      25.8      25.8      25.8

EXHDP   KPA         -11.000   -11.084   -11.247   -11.102   -11.032   -10.981   -11.009   -11.072   -11.107   -11.245
EOILP   KPA              .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
FUELP   KPA           179.5     178.9     174.4     179.8     177.1     181.4     182.5     178.0     175.3     170.1
```

```
                                          SAMPLE DATA

ENGINE  TYPE:                    ENGINE MODEL:                  ENGINE SERIAL NUMBER: 6283999
OPERATOR NAME:                      FUEL TYPE: NEAT                         CELL NAME: CL-4
-------------------------------------------------------------------------------------------------------------
TIME                 19:22:16   19:22:17   19:22:18   19:22:19   19:22:20   19:22:21   19:22:22   19:22:23   19:22:24   19:22:25
SAMPLE                    141        142        143        144        145        146        147        148        149        150
STEP                      141        142        143        144        145        146        147        148        149        150
ENGSP   RPM            2354.0     2364.0     2367.0     2343.0     2353.0     2374.0     2383.0     2313.0     2333.0     2363.0
ETORQ   N-M             232.6      251.5      254.9      244.8      219.8      191.5      183.4      195.5      232.0      251.5
CTORQ   N-M             226.7      244.8      248.0      238.2      213.9      186.4      178.5      190.3      225.7      245.1
FULFA   G/S              5.49       5.85       5.88       5.54       5.57       5.51       5.08       4.53       5.31       5.86
FULFB   G/S              -.01       -.01       -.01       -.01       -.01       -.01       -.00       -.01       -.01       -.01
OBSFC   G/KWH           345.0      338.4      335.4      332.4      370.4      416.9      399.4      344.7      337.6      339.0

EXHTL   DEG-C           311.9      299.4      299.4      299.4      299.4      299.4      299.4      299.4      299.4      293.4
EXCTL   DEG-C          1367.3     1363.3     1363.3     1363.3     1363.3     1363.3     1363.3     1363.3     1363.3     1366.8
EXHTR   DEG-C           307.7      289.7      289.7      289.7      289.7      289.7      289.7      289.7      289.7      251.1
EXCTR   DEG-C           462.6      459.4      459.4      459.4      459.4      459.4      459.4      459.4      459.4      462.6
TIARA   DEG-C            26.1       25.7       25.7       25.7       25.7       25.7       25.7       25.7       25.7       25.8
TIARB   DEG-C            25.7       25.1       25.1       25.1       25.1       25.1       25.1       25.1       25.1       25.7
COLAT   DEG-C            14.9       15.2       15.2       15.2       15.2       15.2       15.2       15.2       15.2       15.4
OILTP   DEG-C            93.3       93.3       93.3       93.3       93.3       93.3       93.3       93.3       93.3       93.4
CYLHT   DEG-C            81.0       83.1       83.1       83.1       83.1       83.1       83.1       83.1       83.1       83.4
H20-O   DEG-C          -658.6     -658.6     -658.6     -658.6     -658.6     -658.6     -658.6     -658.6     -658.6     -658.6
FULTI   DEG-C            20.7       22.8       22.8       22.8       22.8       22.8       22.8       22.8       22.8       23.5
FULTO   DEG-C            25.8       27.4       27.4       27.4       27.4       27.4       27.4       27.4       27.4       26.8

EXHDP   KPA           -11.326    -11.147    -11.091    -11.021    -10.923    -10.965    -11.070    -11.291    -11.315    -11.030
EOILP   KPA                .0         .0         .0         .0         .0         .0         .0         .0         .0         .0
FUELP   KPA             168.0      173.3      174.1      178.8      181.0      184.9      176.1      169.9      168.4      175.2
```

APPENDIX D

Engine Parameter Listing for Engine Operation on Methanol/Diesel Emulsion over MTU-LHD Cycle

ORF - ENGINE PARAMETERS

TEST INITIALIZATION VALUES

```
REPORT REQUEST DATE:                02/13/84
REPORT REQUEST TIME:                18:21:32

TEST INITIALIZATION DATE:           02/13/84
TEST INITIALIZATION TIME:           18:14:39

AVERAGING OF DATA                  150  POINTS

CELL NAME:                          CL-4
TEST ID:
TEST NAME:                          DUR 08
TEST DESCRIPTION:

ENGINE TYPE:
ENGINE MODEL:
ENGINE SERIAL NUMBER:               6283999
ENGINE DISPLACEMENT:                12.800 LITRES      781.0  CU-IN

OPERATOR NAME:

FUEL TYPE:                          D\M 30%
GAS OR DIESEL  :               METH/DIESEL FUEL

AMBIENT DEWPOINT:                  15.60  DEG-C        60.03  DEG-F
AMBIENT VAPOR PRESSURE:             1.77  KPA            52  IN-HG

BAROMETRIC PRESSURE:              101.7  KPA           30.0  IN-HG
```

Fuel samples taken at 6:05 ⇒ 30% $\frac{v}{v}$ MEOH
6:25 ⇒ 29% $\frac{v}{v}$ MEOH

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                        O R F  -  E N G I N E   T E S T   F A C I L I T Y

                                      S A M P L E   D A T A

ENGINE  TYPE:                          ENGINE MODEL:                      ENGINE SERIAL NUMBER  6283999
OPERATOR NAME:                            FUEL TYPE: D\M 30%                          CELL NAME. CL-4
----------------------------------------------------------------------------------------------------------
TIME                   18:17:54  00:00:00  00:00:00  00:00:00  00:00:00  00:00:00  00:00:00  00:00:00  00:00:00  00:00:00
SAMPLE                       75         0         0         0         0         0         0         0         0         0
STEP                         75         0         0         0         0         0         0         0         0         0
ENGSP   RPM              2150.5        .0        .0        .0        .0        .0        .0        .0        .0        .0
ETORQ   N-M               319.0        .0        .0        .0        .0        .0        .0        .0        .0        .0
CTORQ   N-M               314.4        .0        .0        .0        .0        .0        .0        .0        .0        .0
FULFA   G/S                4.88       .00       .00       .00       .00       .00       .00       .00       .00       .00
FULFB   G/S                2.10       .00       .00       .00       .00       .00       .00       .00       .00       .00
OBSFC   G/KWH             244.4        .0        .0        .0        .0        .0        .0        .0        .0        .0

EXHTL   DEG-C             327.0        .0        .0        .0        .0        .0        .0        .0        .0        .0
EXCTL   DEG-C            1374.6        .0        .0        .0        .0        .0        .0        .0        .0        .0
EXHTR   DEG-C             325.2        .0        .0        .0        .0        .0        .0        .0        .0        .0
EXCTR   DEG-C             464.2        .0        .0        .0        .0        .0        .0        .0        .0        .0
TIARA   DEG-C              30.8        .0        .0        .0        .0        .0        .0        .0        .0        .0
TIARB   DEG-C              30.5        .0        .0        .0        .0        .0        .0        .0        .0        .0
COLAT   DEG-C              22.4        .0        .0        .0        .0        .0        .0        .0        .0        .0
OILTP   DEG-C              96.0        .0        .0        .0        .0        .0        .0        .0        .0        .0
CYLHT   DEG-C              92.2        .0        .0        .0        .0        .0        .0        .0        .0        .0
H2O-O   DEG-C            -658.2        .0        .0        .0        .0        .0        .0        .0        .0        .0
FULTI   DEG-C              29.5        .0        .0        .0        .0        .0        .0        .0        .0        .0
FULTO   DEG-C              32.1        .0        .0        .0        .0        .0        .0        .0        .0        .0

EXHDP   KPA             -11.383      .000      .000      .000      .000      .000      .000      .000      .000      .000
EOILP   KPA                  .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
FUELP   KPA               154.7        .0        .0        .0        .0        .0        .0        .0        .0        .0
```

ORF - ENGINE PARAMETERS

TEST INITIALIZATION VALUES

```
REPORT REQUEST DATE:             02/13/84
REPORT REQUEST TIME:             18:25:59

TEST INITIALIZATION DATE:        02/13/84
TEST INITIALIZATION TIME:        18:14:39

AVERAGING OF DATA:               10  POINTS

CELL NAME:                       CL-4
TEST ID:
TEST NAME:                       DUR 08
TEST DESCRIPTION:

ENGINE TYPE:
ENGINE MODEL:
ENGINE SERIAL NUMBER:            6283999
ENGINE DISPLACEMENT:             12.800 LITRES      781.0  CU-IN

OPERATOR NAME:

FUEL TYPE:                       D\M 30%
GAS OR DIESEL  :            METH/DIESEL FUEL

AMBIENT DEWPOINT:               15.60  DEG-C       60.03  DEG-F
AMBIENT VAPOR PRESSURE:          1.77  KPA           .52  IN-HG

BAROMETRIC PRESSURE:            101.7  KPA          30.0  IN-HG
```

Fuel samples taken at 6:05 ⇒ 30% v/v MEOH
6:25 ⇒ 29% v/v MEOH

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                              ORF - ENGINE TEST FACILITY                                  PAGE 2

                                     SAMPLE DATA

ENGINE TYPE:                     ENGINE MODEL:
OPERATOR NAME                      FUEL TYPE: D\M 30%          ENGINE SERIAL NUMBER: 6283999
                                                                         CELL NAME: CL-4
--------------------------------------------------------------------------------------------------------------------
TIME                 18:17:54  18:18:04  18:18:14  18:18:24  18:18:34  18:18:44  18:18:54  18:19:04  18:19:14  18:19:24
SAMPLE                      5        15        25        35        45        55        65        75        85        95
STEP                        5        15        25        35        45        55        65        75        85        95
ENGSP   RPM            2364.7    2350.3    2151.1    1324.2    1541.8    1758.4    2022.4    2355.2    2339.0    2337.9
ETORQ   N-M             233.6     211.9     286.2     443.4     337.6     548.0     375.3     347.2     346.4     328.5
CTORQ   N-M             230.8     209.1     282.3     437.7     333.5     540.5     370.2     340.4     341.7     324.1
FULFA   G/S              4.61      4.24      3.95      4.05      4.82      5.16      5.49      5.64      5.62      5.49
FULFB   G/S              2.11      2.08      2.02      1.25       .53      1.78      2.29      2.62      2.68      2.53
OBSFC   G/KWH           287.0     292.8     220.8     237.1     318.1     184.1     248.7     237.0     236.3     245.9

EXHTL   DEG-C           308.2     307.2     299.7     282.9     288.4     308.0     333.5     352.1     339.3     359.4
EXCTL   DEG-C          1377.3    1376.8    1376.4    1376.4    1376.6    1376.6    1375.9    1369.6    1376.1    1374.5
EXHTR   DEG-C           309.3     307.4     304.7     291.0     287.5     302.5     314.7     349.3     359.1     355.0
EXCTR   DEG-C           466.2     465.9     464.3     464.7     459.5     464.9     464.8     464.8     465.5     464.2
TIARA   DEG-C            31.2      31.2      30.5      30.4      31.2      31.1      31.2      30.6      29.6      31.0
TIARB   DEG-C            31.5      31.2      30.8      31.3      31.5      30.8      30.9      28.3      31.0      31.0
COLAT   DEG-C            24.3      23.3      22.6      21.8      21.7      21.8      21.8      22.4      22.7      22.3
OILTP   DEG-C            96.1      96.3      96.2      96.4      92.6      96.4      96.4      96.6      96.5      96.2
CYLHT   DEG-C            90.7      91.7      90.4      90.0      91.0      93.6      94.2      94.0      90.7      92.3
H2O-O   DEG-C          -656.5    -658.0    -658.4    -658.4    -658.4    -658.4    -658.3    -658.3    -658.3    -658.3
FULTI   DEG-C            30.1      30.1      29.6      30.0      29.2      29.1      28.4      29.4      29.8      29.9
FULTO   DEG-C            34.2      32.8      33.0      32.2      30.6      31.3      31.3      28.6      33.1      33.4

EXHDP   KPA           -11.190   -11.223   -11.451   -11.646   -11.236   -11.681   -11.309   -11.501   -11.421   -11.423
EOILP   KPA                .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
FUELP   KPA             158.7     158.4     163.0     175.9     180.5     170.1     161.7     139.7     138.9     140.1
```

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                              O R F  -  E N G I N E  T E S T  F A C I L I T Y                              PAGE  3

                                             S A M P L E  D A T A

ENGINE  TYPE:                         ENGINE MODEL:                        ENGINE SERIAL NUMBER: 6283999
OPERATOR NAME:                            FUEL TYPE: D\M 30%                           CELL NAME: CL-4
---------------------------------------------------------------------------------------------------------------
TIME                18:19:34  18:19:44  18:19:54  18:20:04  18:20:14  00:00:00  00:00:00  00:00:00  00:00:00  00:00:00
SAMPLE                   105       115       125       135       145         0         0         0         0         0
STEP                     105       115       125       135       145         0         0         0         0         0
ENGSP     RPM         2327.4    2324.1    2356.6    2352.5    2352.4        .0        .0        .0        .0        .0
ETORQ     N-M          338.4     341.8     218.2     203.0     225.6        .0        .0        .0        .0        .0
CTORQ     N-M          333.7     337.0     214.0     200.1     221.3        .0        .0        .0        .0        .0
FULFA     G/S           5.49      5.54      4.38      4.19      4.48       .00       .00       .00       .00       .00
FULFB     G/S           2.57      2.58      2.40      2.06      2.06       .00       .00       .00       .00       .00
OBSFC     G/KWH        239.8     239.9     292.9     301.3     290.5        .0        .0        .0        .0        .0

EXHTL     DEG-C        356.0     345.5     360.4     337.5     326.3        .0        .0        .0        .0        .0
EXCTL     DEG-C       1376.1    1375.5    1366.7    1375.3    1369.5        .0        .0        .0        .0        .0
EXHTR     DEG-C        335.0     356.1     356.1     329.6     320.3        .0        .0        .0        .0        .0
EXCTR     DEG-C        464.0     465.0     465.3     459.1     464.6        .0        .0        .0        .0        .0
TIARA     DEG-C         30.8      30.4      31.3      31.1      31.1        .0        .0        .0        .0        .0
TIARB     DEG-C         30.8      30.8      28.3      30.6      28.6        .0        .0        .0        .0        .0
COLAT     DEG-C         22.4      22.6      22.3      21.9      21.9        .0        .0        .0        .0        .0
OILTP     DEG-C         96.5      96.6      96.4      93.9      96.8        .0        .0        .0        .0        .0
CYLHT     DEG-C         93.1      91.4      93.5      93.3      93.7        .0        .0        .0        .0        .0
H2O-O     DEG-C       -658.3    -658.3    -658.3    -658.3    -658.3        .0        .0        .0        .0        .0
FULTI     DEG-C         29.8      29.9      30.3      28.5      28.6        .0        .0        .0        .0        .0
FULTO     DEG-C         33.5      33.6      30.1      33.7      30.9        .0        .0        .0        .0        .0

EXHDP     KPA        -11.421   -11.427   -11.187   -11.297   -11.339      .000      .000      .000      .000      .000
EOILP     KPA             .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
FUELP     KPA          134.4     137.2     154.9     154.6     152.7        .0        .0        .0        .0        .0
```

ORF - ENGINE PARAMETERS

TEST INITIALIZATION VALUES

```
REPORT REQUEST DATE:          02/13/84
REPORT REQUEST TIME:          18:28:36

TEST INITIALIZATION DATE:     02/13/84
TEST INITIALIZATION TIME:     18:14:39

CELL NAME:                    CL-4
TEST ID:
TEST NAME:                    DUR 08
TEST DESCRIPTION:

ENGINE TYPE:
ENGINE MODEL:
ENGINE SERIAL NUMBER:         6283999
ENGINE DISPLACEMENT:          12.800 LITRES     781.0  CU-IN

OPERATOR NAME:

FUEL TYPE:                    DVM 30%
GAS OR DIESEL  :        METH /DIESEL FUEL

AMBIENT DEWPOINT:             15.60  DEG-C      60.03  DEG-F
AMBIENT VAPOR PRESSURE:        1.77  KPA          .52  IN-HG

BAROMETRIC PRESSURE:          101.7  KPA         30.0  IN-HG
```

Fuel sample taken at 6:05 ⇒ 30% $\frac{v}{v}$ MEOH
6:25 ⇒ 29% $\frac{v}{v}$ MEOH

ORF - ENGINE TEST FACILITY

SAMPLE DATA

ENGINE TYPE
OPERATOR NAME

ENGINE MODEL:
FUEL TYPE: D\M 30%

ENGINE SERIAL NUMBER: 6283999
CELL NAME: CL-4

TIME		18:17:54	18:17:55	18:17:56	18:17:57	18:17:58	18:17:59	18:18:00	18:18:01	18:18:02	18:18:03
SAMPLE		1	2	3	4	5	6	7	8	9	10
STEP		1	2	3	4	5	6	7	8	9	10
ENGSP	RPM	2378.0	2382.0	2399.0	2329.0	2266.0	2344.0	2363.0	2392.0	2404.0	2390.0
ETORQ	N-M	235.3	215.8	236.7	327.0	340.5	271.7	210.4	167.2	150.4	181.4
CTORQ	N-M	232.3	213.0	233.7	322.9	336.5	268.5	207.9	165.2	148.6	179.2
FULFA	G/S	4.72	4.61	4.77	4.69	4.82	5.81	4.76	4.24	3.97	3.72
FULFB	G/S	2.03	2.05	2.06	2.07	2.09	2.10	2.15	2.19	2.19	2.17
OBSFC	G/KWH	290.2	308.3	289.0	211.5	214.9	313.4	329.5	364.8	377.6	294.9
EXHTL	DEG-C	306.9	306.9	306.9	306.9	309.2	309.2	309.2	309.2	309.2	309.2
EXCTL	DEG-C	1376.6	1376.6	1376.6	1376.6	1377.7	1377.7	1377.7	1377.7	1377.7	1377.7
EXHTR	DEG-C	311.5	311.5	311.5	311.5	307.8	307.8	307.8	307.8	307.8	307.8
EXCTR	DEG-C	465.4	465.4	465.4	465.4	466.8	466.8	466.8	466.8	466.8	466.8
TIARA	DEG-C	31.4	31.4	31.4	31.4	31.0	31.0	31.0	31.0	31.0	31.0
TIARB	DEG-C	31.3	31.3	31.3	31.3	31.7	31.7	31.7	31.7	31.7	31.7
COLAT	DEG-C	24.3	24.3	24.3	24.3	24.4	24.4	24.4	24.4	24.4	24.4
OILTP	DEG-C	96.5	96.5	96.5	96.5	95.9	95.9	95.9	95.9	95.9	95.9
CYLHT	DEG-C	88.3	88.3	88.3	88.3	92.3	92.3	92.3	92.3	92.3	92.3
H2O-O	DEG-C	-656.5	-656.5	-656.5	-656.5	-656.5	-656.5	-656.5	-656.5	-656.5	-656.5
FULTI	DEG-C	29.2	29.2	29.2	29.2	30.7	30.7	30.7	30.7	30.7	30.7
FULTO	DEG-C	35.2	35.2	35.2	35.2	33.5	33.5	33.5	33.5	33.5	33.5
EXHDP	KPA	-10.995	-11.207	-11.744	-11.532	-10.850	-10.862	-10.855	-10.969	-11.189	-11.693
EOILP	KPA	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
FUELP	KPA	158.6	151.1	144.6	160.6	155.8	150.7	172.2	165.4	166.8	161.0

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                                 ORF - ENGINE TEST FACILITY

                                        SAMPLE DATA

ENGINE  TYPE:                  ENGINE MODEL:                     ENGINE SERIAL NUMBER: 6283999
OPERATOR NAME:                      FUEL TYPE: D\M 30%                      CELL NAME: CL-4
-----------------------------------------------------------------------------------------------------
TIME                18:18:04  18:18:05  18:18:06  18:18:07  18:18:08  18:18:09  18:18:10  18:18:11  18:18:12  18:18:13
SAMPLE                    11        12        13        14        15        16        17        18        19        20
STEP                      11        12        13        14        15        16        17        18        19        20
ENGSP     RPM         2305.0    2337.0    2362.0    2394.0    2372.0    2329.0    2329.0    2348.0    2388.0    2339.0
ETORQ     N-M          235.3     252.2     229.3     193.5     179.4     193.5     211.7     211.7     204.3     207.7
CTORQ     N-M          232.5     249.2     226.2     191.0     177.0     191.0     208.9     208.9     201.6     204.7
FULFA     G/S           3.49      4.81      5.02      4.67      3.81      3.42      4.07      4.56      4.69      3.88
FULFB     G/S           2.12      2.08      2.07      2.10      2.12      2.10      2.06      2.03      2.03      2.05
OBSFC     G/KWH        221.0     280.4     318.8     346.4     307.9     261.0     283.5     315.1     330.4     274.5

EXHTL     DEG-C        309.2     309.2     306.4     306.4     306.4     306.4     306.4     306.4     306.4     308.3
EXCTL     DEG-C       1377.7    1377.7    1376.6    1376.6    1376.6    1376.6    1376.6    1376.6    1376.6    1376.6
EXHTR     DEG-C        307.8     307.8     307.8     307.8     307.8     307.8     307.8     307.8     307.8     304.1
EXCTR     DEG-C        466.8     466.8     465.9     465.9     465.9     465.9     465.9     465.9     465.9     464.5
TIARA     DEG-C         31.0      31.0      31.2      31.2      31.2      31.2      31.2      31.2      31.2      31.1
TIARB     DEG-C         31.7      31.7      31.1      31.1      31.1      31.1      31.1      31.1      31.1      30.6
COLAT     DEG-C         24.4      24.4      23.1      23.1      23.1      23.1      23.1      23.1      23.1      22.9
OILTP     DEG-C         95.9      95.9      96.4      96.4      96.4      96.4      96.4      96.4      96.4      96.2
CYLHT     DEG-C         92.3      92.3      91.6      91.6      91.6      91.6      91.6      91.6      91.6      91.9
H2O-O     DEG-C       -656.5    -656.5    -658.4    -658.4    -658.4    -658.4    -658.4    -658.4    -658.4    -658.4
FULTI     DEG-C         30.7      30.7      30.1      30.1      30.1      30.1      30.1      30.1      30.1      29.5
FULTO     DEG-C         33.5      33.5      32.5      32.5      32.5      32.5      32.5      32.5      32.5      33.2

EXHDP     KPA        -11.443   -11.149   -10.934   -11.088   -11.245   -11.371   -11.224   -11.158   -11.254   -11.361
EOILP     KPA             .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
FUELP     KPA          159.5     142.9     157.2     163.1     171.6     157.1     152.4     147.7     160.6     172.1
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                              O R F  -  E N G I N E  T E S T  F A C I L I T Y                        PAGE  4

                                            S A M P L E  D A T A

ENGINE  TYPE:                          ENGINE MODEL:                       ENGINE SERIAL NUMBER: 6283999
OPERATOR NAME                              FUEL TYPE: D\M 30%                         CELL NAME: CL-4
------------------------------------------------------------------------------------------------------------
TIME                18.18.14  18:18:15  18:18:16  18:18:17  18:18:18  18:18:19  18:18:20  18:18:21  18:18:22  18:18:23
SAMPLE                    21        22        23        24        25        26        27        28        29        30
STEP                      21        22        23        24        25        26        27        28        29        30
ENGSP    RPM          2349.0    2361.0    2362.0    2340.0    2321.0    2098.0    2120.0    1995.0    1812.0    1753.0
ETORQ    N-M           220.5     235.3     245.4     249.5     306.1     325.7     293.3     333.1     350.6     302.8
CTORQ    N-M           217.4     232.0     242.0     245.9     301.8     321.0     289.1     328.7     346.0     298.8
FULFA    G/S            4.24      4.57      4.71      4.52      4.91      2.83      4.64      3.25      2.72      3.14
FULFB    G/S            2.04      2.03      2.04      2.05      2.07      2.08      2.04      2.00      1.95      1.86
OBSFC    G/KWH         281.7     282.8     279.4     266.2     237.7     142.6     256.3     168.2     147.1     203.7

EXHTL    DEG-C         308.3     308.3     308.3     308.3     308.3     308.3     308.3     279.6     279.6     279.6
EXCTL    DEG-C        1376.6    1376.6    1376.6    1376.6    1376.6    1376.6    1376.6    1376.0    1376.0    1376.0
EXHTR    DEG-C         304.1     304.1     304.1     304.1     304.1     304.1     304.1     306.0     306.0     306.0
EXCTR    DEG-C         464.5     464.5     464.5     464.5     464.5     464.5     464.5     463.6     463.6     463.6
TIARA    DEG-C          31.1      31.1      31.1      31.1      31.1      31.1      31.1      29.1      29.1      29.1
TIARB    DEG-C          30.6      30.6      30.6      30.6      30.6      30.6      30.6      31.1      31.1      31.1
COLAT    DEG-C          22.9      22.9      22.9      22.9      22.9      22.9      22.9      22.0      22.0      22.0
OILTP    DEG-C          96.2      96.2      96.2      96.2      96.2      96.2      96.2      96.4      96.4      96.4
CYLHT    DEG-C          91.9      91.9      91.9      91.9      91.9      91.9      91.9      86.9      86.9      86.9
H2O-O    DEG-C        -658.4    -658.4    -658.4    -658.4    -658.4    -658.4    -658.4    -658.4    -658.4    -658.4
FULTI    DEG-C          29.5      29.5      29.5      29.5      29.5      29.5      29.5      29.9      29.9      29.9
FULTO    DEG-C          33.2      33.2      33.2      33.2      33.2      33.2      33.2      32.5      32.5      32.5

EXHDP    KPA         -11.422   -11.445   -11.375   -11.721   -11.728   -11.224   -11.600   -11.677   -11.177   -11.144
EOILP    KPA              .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
FUELP    KPA           151.9     166.3     143.0     160.1     141.4     167.7     152.7     183.8     182.6     180.3
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                        ORF - ENGINE TEST FACILITY

                               SAMPLE DATA

ENGINE TYPE:                 ENGINE MODEL:                ENGINE SERIAL NUMBER: 6283999
OPERATOR NAME                  FUEL TYPE: D\M 30%                   CELL NAME: CL-4
----------------------------------------------------------------------------------------------------------
TIME                18:18:24  18:18:25  18:18:26  18:18:27  18:18:28  18:18:29  18:18:30  18:18:31  18:18:32  18:18:33
SAMPLE                    31        32        33        34        35        36        37        38        39        40
STEP                      31        32        33        34        35        36        37        38        39        40
ENGSP   RPM           1661.0    1539.0    1447.0    1340.0    1286.0    1257.0    1180.0    1156.0    1194.0    1182.0
ETORQ   N-M            274.4     308.8     369.5     389.1     391.8     437.0     504.4     563.0     598.1     597.4
CTORQ   N-M            270.8     304.8     364.6     383.9     386.9     431.5     498.1     556.1     590.7     590.0
FULFA   G/S             2.57      2.42      2.60      2.61      2.84      3.75      4.92      5.86      6.37      6.54
FULFB   G/S             1.78      1.69      1.56      1.47      1.38      1.24      1.08       .92       .77       .65
OBSFC   G/KWH          194.1     174.8     167.2     171.8     194.0     234.9     284.4     309.7     306.9     318.3

EXHTL   DEG-C          279.6     279.6     279.6     279.6     285.1     285.1     285.1     285.1     285.1     285.1
EXCTL   DEG-C         1376.0    1376.0    1376.0    1376.0    1376.6    1376.6    1376.6    1376.6    1376.6    1376.6
EXHTR   DEG-C          306.0     306.0     306.0     306.0     281.0     281.0     281.0     281.0     281.0     281.0
EXCTR   DEG-C          463.6     463.6     463.6     463.6     465.4     465.4     465.4     465.4     465.4     465.4
TIARA   DEG-C           29.1      29.1      29.1      29.1      31.2      31.2      31.2      31.2      31.2      31.2
TIARB   DEG-C           31.1      31.1      31.1      31.1      31.5      31.5      31.5      31.5      31.5      31.5
COLAT   DEG-C           22.0      22.0      22.0      22.0      21.7      21.7      21.7      21.7      21.7      21.7
OILTP   DEG-C           96.4      96.4      96.4      96.4      96.4      96.4      96.4      96.4      96.4      96.4
CYLHT   DEG-C           86.9      86.9      86.9      86.9      92.1      92.1      92.1      92.1      92.1      92.1
H2O-O   DEG-C         -658.4    -658.4    -658.4    -658.4    -658.4    -658.4    -658.4    -658.4    -658.4    -658.4
FULTI   DEG-C           29.9      29.9      29.9      29.9      30.1      30.1      30.1      30.1      30.1      30.1
FULTO   DEG-C           32.5      32.5      32.5      32.5      31.9      31.9      31.9      31.9      31.9      31.9

EXHDP   KPA          -11.579   -11.700   -11.571   -11.539   -11.639   -11.721   -11.758   -11.749   -11.712   -11.494
EOILP   KPA               .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
FUELP   KPA            179.3     177.6     183.7     183.5     181.6     174.6     171.0     168.8     168.2     171.1
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ORF - ENGINE TEST FACILITY

SAMPLE DATA

ENGINE TYPE:
OPERATOR NAME:

ENGINE MODEL:
FUEL TYPE: D\M 30%

ENGINE SERIAL NUMBER: 6283999
CELL NAME: CL-4

TIME		18:18:34	18:18:35	18:18:36	18:18:37	18:18:38	18:18:39	18:18:40	18:18:41	18:18:42	18:18:43
SAMPLE		41	42	43	44	45	46	47	48	49	50
STEP		41	42	43	44	45	46	47	48	49	50
ENGSP	RPM	1209.0	1255.0	1443.0	1479.0	1497.0	1549.0	1619.0	1717.0	1827.0	1823.0
ETORQ	N-M	549.6	455.8	370.2	288.6	221.8	175.3	177.3	267.0	384.4	486.2
CTORQ	N-M	542.8	450.3	365.7	285.1	219.2	173.2	175.2	263.8	379.7	479.2
FULFA	G/S	6.64	6.90	7.33	4.83	3.19	2.79	2.83	3.82	4.95	4.87
FULFB	G/S	.54	.45	.38	.34	.41	.48	.53	.60	.70	.86
OBSFC	G/KWH	343.4	414.8	472.0	389.1	330.0	353.2	339.4	286.5	242.5	189.0
EXHTL	DEG-C	285.1	288.4	288.4	288.4	288.4	288.4	288.4	288.4	288.4	292.1
EXCTL	DEG-C	1376.6	1376.6	1376.6	1376.6	1376.6	1376.6	1376.6	1376.6	1376.6	1376.6
EXHTR	DEG-C	281.0	288.4	288.4	288.4	288.4	288.4	288.4	288.4	288.4	286.5
EXCTR	DEG-C	465.4	458.1	458.1	458.1	458.1	458.1	458.1	458.1	458.1	464.5
TIARA	DEG-C	31.2	31.2	31.2	31.2	31.2	31.2	31.2	31.2	31.2	31.1
TIARB	DEG-C	31.5	31.6	31.6	31.6	31.6	31.6	31.6	31.6	31.6	30.6
COLAT	DEG-C	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7	21.7
OILTP	DEG-C	96.4	91.7	91.7	91.7	91.7	91.7	91.7	91.7	91.7	96.4
CYLHT	DEG-C	92.1	90.6	90.6	90.6	90.6	90.6	90.6	90.6	90.6	93.3
H20-O	DEG-C	-658.4	-658.4	-658.4	-658.4	-658.4	-658.4	-658.4	-658.4	-658.4	-658.4
FULTI	DEG-C	30.1	29.1	29.1	29.1	29.1	29.1	29.1	29.1	29.1	29.1
FULTO	DEG-C	31.9	30.4	30.4	30.4	30.4	30.4	30.4	30.4	30.4	30.8
EXHDP	KPA	-11.046	-10.841	-10.794	-10.764	-10.782	-10.979	-11.712	-11.803	-11.819	-11.821
EOILP	KPA	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
FUELP	KPA	171.3	187.0	184.0	198.6	189.4	186.5	176.8	175.0	167.7	169.2

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                    ORF - ENGINE TEST FACILITY                                         PAGE  7

                              SAMPLE DATA

ENGINE TYPE:                     ENGINE MODEL:                  ENGINE SERIAL NUMBER: 6283999
OPERATOR NAME:                      FUEL TYPE: D\M 30%                      CELL NAME: CL-4
----------------------------------------------------------------------------------------------------
TIME                  18:18:44   18:18:45   18:18:46   18:18:47   18:18:48   18:18:49   18:18:50   18:18:51   18:18:52   18:18:53
SAMPLE                      51         52         53         54         55         56         57         58         59         60
STEP                        51         52         53         54         55         56         57         58         59         60
ENGSP    RPM            1767.0     1779.0     1836.0     1880.0     1917.0     1872.0     1803.0     1623.0     1613.0     1494.0
ETORQ    N-M             551.6      576.5      588.7      594.7      583.9      573.2      587.3      487.5      437.6      499.0
CTORQ    N-M             543.7      568.3      580.3      586.3      575.6      565.0      579.6      481.1      431.9      492.5
FULFA    G/S              5.07       5.89       6.38       6.58       6.45       5.84       5.15       3.64       3.39       3.20
FULFB    G/S              1.03       1.21       1.40       1.61       1.81       2.00       2.13       2.20       2.20       2.16
OBSFC    G/KWH           179.0      197.4      202.9      202.4      198.2      187.1      167.1      158.2      165.4      147.4

EXHTL    DEG-C           292.1      292.1      292.1      292.1      292.1      292.1      331.9      331.9      331.9      331.9
EXCTL    DEG-C          1376.6     1376.6     1376.6     1376.6     1376.6     1376.6     1376.7     1376.7     1376.7     1376.7
EXHTR    DEG-C           286.5      286.5      286.5      286.5      286.5      286.5      326.3      326.3      326.3      326.3
EXCTR    DEG-C           464.5      464.5      464.5      464.5      464.5      464.5      465.5      465.5      465.5      465.5
TIARA    DEG-C            31.1       31.1       31.1       31.1       31.1       31.1       31.0       31.0       31.0       31.0
TIARB    DEG-C            30.6       30.6       30.6       30.6       30.6       30.6       31.2       31.2       31.2       31.2
COLAT    DEG-C            21.7       21.7       21.7       21.7       21.7       21.7       22.0       22.0       22.0       22.0
OILTP    DEG-C            96.4       96.4       96.4       96.4       96.4       96.4       96.4       96.4       96.4       96.4
CYLHT    DEG-C            93.3       93.3       93.3       93.3       93.3       93.3       94.2       94.2       94.2       94.2
H2O-O    DEG-C          -658.4     -658.4     -658.4     -658.4     -658.4     -658.4     -658.3     -658.3     -658.3     -658.3
FULTI    DEG-C            29.1       29.1       29.1       29.1       29.1       29.1       29.2       29.2       29.2       29.2
FULTO    DEG-C            30.8       30.8       30.8       30.8       30.8       30.8       32.1       32.1       32.1       32.1

EXHDP    KPA           -11.810    -11.814    -11.819    -11.796    -11.749    -11.814    -11.340    -11.217    -11.733    -11.721
EOILP    KPA                .0         .0         .0         .0         .0         .0         .0         .0         .0         .0
FUELP    KPA             162.9      167.3      160.0      161.6      170.6      170.0      178.5      188.8      172.2      169.2
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                         O R F  -  E N G I N E  T E S T  F A C I L I T Y

                                    S A M P L E  D A T A

ENGINE  TYPE:                      ENGINE MODEL:                ENGINE SERIAL NUMBER: 6283999
OPERATOR NAME:                        FUEL TYPE  D\M 30%                  CELL NAME: CL-4
-----------------------------------------------------------------------------------------------------
TIME                18:18:54  18:18:55  18:18:56  18:18:57  18:18:58  18:18:59  18:19:00  18:19:01  18:19:02  18:19:03
SAMPLE                    61        62        63        64        65        66        67        68        69        70
STEP                      61        62        63        64        65        66        67        68        69        70
ENGSP    RPM          1459.0    1476.0    1593.0    1757.0    2012.0    2297.0    2405.0    2412.0    2411.0    2402.0
ETORQ    N-M           557.0     565.1     514.5     404.6     312.9     269.7     261.0     269.0     285.9     313.6
CTORQ    N-M           549.7     557.7     507.8     399.0     308.5     266.0     257.3     265.3     281.9     309.2
FULFA    G/S            3.83      4.58      4.99      5.60      6.57      7.49      6.42      5.16      5.03      5.24
FULFB    G/S            2.08      2.04      2.04      2.09      2.17      2.29      2.44      2.57      2.61      2.60
OBSFC    G/KWH         162.1     188.8     209.5     270.8     358.8     415.9     351.5     273.3     250.7     239.0

EXHTL    DEG-C         331.9     331.9     331.9     334.2     334.2     334.2     334.2     334.2     334.2     334.2
EXCTL    DEG-C        1376.7    1376.7    1376.7    1375.5    1375.5    1375.5    1375.5    1375.5    1375.5    1375.5
EXHTR    DEG-C         326.3     326.3     326.3     309.7     309.7     309.7     309.7     309.7     309.7     309.7
EXCTR    DEG-C         465.5     465.5     465.5     464.6     464.6     464.6     464.6     464.6     464.6     464.6
TIARA    DEG-C          31.0      31.0      31.0      31.3      31.3      31.3      31.3      31.3      31.3      31.3
TIARB    DEG-C          31.2      31.2      31.2      30.8      30.8      30.8      30.8      30.8      30.8      30.8
COLAT    DEG-C          22.0      22.0      22.0      21.7      21.7      21.7      21.7      21.7      21.7      21.7
OILTP    DEG-C          96.4      96.4      96.4      96.4      96.4      96.4      96.4      96.4      96.4      96.4
CYLHT    DEG-C          94.2      94.2      94.2      94.3      94.3      94.3      94.3      94.3      94.3      94.3
H2O-O    DEG-C        -658.3    -658.3    -658.3    -658.3    -658.3    -658.3    -658.3    -658.3    -658.3    -658.3
FULTI    DEG-C          29.2      29.2      29.2      28.1      28.1      28.1      28.1      28.1      28.1      28.1
FULTO    DEG-C          32.1      32.1      32.1      30.9      30.9      30.9      30.9      30.9      30.9      30.9

EXHDP    KPA         -11.660   -11.399   -10.913   -10.843   -11.035   -11.238   -11.357   -11.431   -11.590   -11.623
EOILP    KPA              .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
FUELP    KPA           172.5     170.7     182.4     185.9     174.7     125.1     162.9     158.8     144.0     139.9
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                              O R F  -  E N G I N E  T E S T  F A C I L I T Y

                                           S A M P L E  D A T A

ENGINE  TYPE:                   ENGINE MODEL:                  ENGINE SERIAL NUMBER. 6283999
OPERATOR NAME:                     FUEL TYPE: D\M 30%                       CELL NAME: CL-4
--------------------------------------------------------------------------------------------------------
TIME                 18:19:04  18:19:05  18:19:06  18:19:07  18:19:08  18:19:09  18:19:10  18:19:11  18:19:12  18:19:13
SAMPLE                     71        72        73        74        75        76        77        78        79        80
STEP                       71        72        73        74        75        76        77        78        79        80
ENGSP   RPM            2385.0    2390.0    2405.0    2393.0    2384.0    2387.0    2304.0    2233.0    2347.0    2324.0
ETORQ   N-M             352.7     366.1     358.7     358.7     357.4     337.8     322.3     329.1     343.9     345.2
CTORQ   N-M             347.8     358.0     350.8     350.8     349.5     330.3     315.2     321.8     339.2     340.5
FULFA   G/S              5.65      6.09      6.08      5.97      5.95      5.85      4.50      4.19      6.55      5.53
FULFB   G/S              2.60      2.59      2.60      2.62      2.65      2.66      2.68      2.65      2.59      2.59
OBSFC   G/KWH           231.0     239.2     242.4     238.9     240.1     249.3     208.6     196.3     279.0     236.8

EXHTL   DEG-C           334.2     360.9     360.9     360.9     360.9     360.9     360.9     360.9     330.5     330.5
EXCTL   DEG-C          1375.5    1366.9    1366.9    1366.9    1366.9    1366.9    1366.9    1366.9    1376.1    1376.1
EXHTR   DEG-C           309.7     353.5     353.5     353.5     353.5     353.5     353.5     353.5     354.5     354.5
EXCTR   DEG-C           464.6     464.6     464.6     464.6     464.6     464.6     464.6     464.6     465.5     465.5
TIARA   DEG-C            31.3      31.0      31.0      31.0      31.0      31.0      31.0      31.0      28.9      28.9
TIARB   DEG-C            30.8      27.2      27.2      27.2      27.2      27.2      27.2      27.2      30.9      30.9
COLAT   DEG-C            21.7      22.3      22.3      22.3      22.3      22.3      22.3      22.3      23.0      23.0
OILTP   DEG-C            96.4      96.7      96.7      96.7      96.7      96.7      96.7      96.7      96.3      96.3
CYLHT   DEG-C            94.3      94.9      94.9      94.9      94.9      94.9      94.9      94.9      90.4      90.4
H2O-O   DEG-C          -658.3    -658.3    -658.3    -658.3    -658.3    -658.3    -658.3    -658.3    -658.3    -658.3
FULTI   DEG-C            28.1      29.5      29.5      29.5      29.5      29.5      29.5      29.5      29.7      29.7
FULTO   DEG-C            30.9      26.9      26.9      26.9      26.9      26.9      26.9      26.9      33.4      33.4

EXHDP   KPA           -11.637   -11.520   -11.532   -11.541   -11.373   -11.329   -11.511   -11.501   -11.541   -11.527
EOILP   KPA                .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
FUELP   KPA             130.0     135.1     134.0     135.2     133.2     139.2     173.1     134.1     132.0     151.1
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                              ORF - ENGINE TEST FACILITY                              PAGE 10

                                      SAMPLE DATA

ENGINE  TYPE                 ENGINE MODEL:                  ENGINE SERIAL NUMBER: 6283999
OPERATOR NAME                   FUEL TYPE: D\M 30%                     CELL NAME: CL-4
-----------------------------------------------------------------------------------------------------------
TIME               18:19:14  18:19:15  18:19:16  18:19:17  18:19:18  18:19:19  18:19:20  18:19:21  18:19:22  18:19:23
SAMPLE                  81        82        83        84        85        86        87        88        89        90
STEP                    81        82        83        84        85        86        87        88        89        90
ENGSP   RPM         2322.0    2301.0    2325.0    2313.0    2360.0    2359.0    2293.0    2386.0    2419.0    2312.0
ETORQ   N-M          356.0     428.9     465.3     399.2     327.7     316.2     294.0     258.9     267.0     350.6
CTORQ   N-M          351.2     423.0     458.9     393.8     323.2     311.9     290.1     255.5     263.5     346.0
FULFA   G/S           5.38      5.92      7.06      6.47      6.09      5.26      4.43      5.90      5.20      4.45
FULFB   G/S           2.62      2.62      2.64      2.70      2.76      2.78      2.75      2.69      2.65      2.63
OBSFC   G/KWH        223.9     206.2     224.5     241.1     270.7     242.4     225.8     328.5     276.8     188.5

EXHTL   DEG-C        330.5     330.5     330.5     330.5     330.5     330.5     352.6     352.6     352.6     352.6
EXCTL   DEG-C       1376.1    1376.1    1376.1    1376.1    1376.1    1376.1    1376.1    1376.1    1376.1    1376.1
EXHTR   DEG-C        354.5     354.5     354.5     354.5     354.5     354.5     366.0     366.0     366.0     366.0
EXCTR   DEG-C        465.5     465.5     465.5     465.5     465.5     465.5     465.5     465.5     465.5     465.5
TIARA   DEG-C         28.9      28.9      28.9      28.9      28.9      28.9      30.6      30.6      30.6      30.6
TIARB   DEG-C         30.9      30.9      30.9      30.9      30.9      30.9      31.0      31.0      31.0      31.0
COLAT   DEG-C         23.0      23.0      23.0      23.0      23.0      23.0      22.2      22.2      22.2      22.2
OILTP   DEG-C         96.3      96.3      96.3      96.3      96.3      96.3      96.7      96.7      96.7      96.7
CYLHT   DEG-C         90.4      90.4      90.4      90.4      90.4      90.4      91.1      91.1      91.1      91.1
H2O-O   DEG-C       -658.3    -658.3    -658.3    -658.3    -658.3    -658.3    -658.3    -658.3    -658.3    -658.3
FULTI   DEG-C         29.7      29.7      29.7      29.7      29.7      29.7      29.9      29.9      29.9      29.9
FULTO   DEG-C         33.4      33.4      33.4      33.4      33.4      33.4      32.8      32.8      32.8      32.8

EXHDP   KPA        -11.798   -11.765   -11.291   -11.137   -11.282   -11.301   -11.058   -11.226   -11.817   -11.536
EOILP   KPA             .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
FUELP   KPA          128.0     115.7     120.4     149.8     132.6     153.1     155.7     145.5     141.5     146.6
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                         O R F  -  E N G I N E   T E S T   F A C I L I T Y                        PAGE 11

                                        S A M P L E   D A T A

ENGINE  TYPE:                    ENGINE MODEL:                    ENGINE SERIAL NUMBER: 6283999
OPERATOR NAME:                       FUEL TYPE: D\M 30%                     CELL NAME: CL-4
-----------------------------------------------------------------------------------------------------------------
TIME                 18:19:24  18:19:25  18:19:26  18:19:27  18:19:28  18:19:29  18:19:30  18:19:31  18:19:32  18:19:33
SAMPLE                     91        92        93        94        95        96        97        98        99       100
STEP                       91        92        93        94        95        96        97        98        99       100
ENGSP    RPM           2263.0    2398.0    2411.0    2346.0    2271.0    2360.0    2342.0    2302.0    2349.0    2337.0
ETORQ    N-M            350.6     278.5     253.5     284.6     334.5     362.8     362.8     358.1     353.3     346.6
CTORQ    N-M            346.0     274.8     250.2     280.7     329.9     357.8     357.8     353.2     348.5     341.9
FULFA    G/S             5.10      6.47      5.31      4.17      4.55      6.49      5.79      5.37      6.16      5.51
FULFB    G/S             2.58      2.54      2.56      2.57      2.52      2.47      2.49      2.51      2.53      2.55
OBSFC    G/KWH          221.0     333.0     298.8     214.8     206.0     260.5     234.4     224.2     255.3     233.9

EXHTL    DEG-C          352.6     352.6     352.6     362.3     362.3     362.3     362.3     362.3     362.3     362.3
EXCTL    DEG-C         1376.1    1376.1    1376.1    1373.8    1373.8    1373.8    1373.8    1373.8    1373.8    1373.8
EXHTR    DEG-C          366.0     366.0     366.0     350.3     350.3     350.3     350.3     350.3     350.3     350.3
EXCTR    DEG-C          465.5     465.5     465.5     463.7     463.7     463.7     463.7     463.7     463.7     463.7
TIARA    DEG-C           30.6      30.6      30.6      31.2      31.2      31.2      31.2      31.2      31.2      31.2
TIARB    DEG-C           31.0      31.0      31.0      30.9      30.9      30.9      30.9      30.9      30.9      30.9
COLAT    DEG-C           22.2      22.2      22.2      22.3      22.3      22.3      22.3      22.3      22.3      22.3
OILTP    DEG-C           96.7      96.7      96.7      96.0      96.0      96.0      96.0      96.0      96.0      96.0
CYLHT    DEG-C           91.1      91.1      91.1      92.8      92.8      92.8      92.8      92.8      92.8      92.8
H20-O    DEG-C         -658.3    -658.3    -658.3    -658.3    -658.3    -658.3    -658.3    -658.3    -658.3    -658.3
FULTI    DEG-C           29.9      29.9      29.9      29.9      29.9      29.9      29.9      29.9      29.9      29.9
FULTO    DEG-C           32.8      32.8      32.8      33.6      33.6      33.6      33.6      33.6      33.6      33.6

EXHDP    KPA          -10.913   -11.147   -11.548   -11.639   -11.560   -11.546   -11.497   -11.473   -11.464   -11.448
EOILP    KPA               .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
FUELP    KPA            142.1     144.1     141.9     161.0     133.2     124.7     146.4     133.7     124.1     150.1
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ORF - ENGINE TEST FACILITY

SAMPLE DATA

ENGINE TYPE:
OPERATOR NAME:
ENGINE MODEL:
FUEL TYPE: D\M 30%
ENGINE SERIAL NUMBER: 6283999
CELL NAME: CL-4

TIME		18:19:34	18:19:35	18:19:36	18:19:37	18:19:38	18:19:39	18:19:40	18:19:41	18:19:42	18:19:43
SAMPLE		101	102	103	104	105	106	107	108	109	110
STEP		101	102	103	104	105	106	107	108	109	110
ENGSP	RPM	2312.0	2330.0	2344.0	2336.0	2306.0	2323.0	2310.0	2320.0	2335.0	2358.0
ETORQ	N-M	343.2	333.8	325.7	343.9	359.4	354.7	345.2	334.5	322.3	321.0
CTORQ	N-M	338.5	329.2	321.2	339.1	354.4	349.8	340.5	329.8	317.9	316.6
FULFA	G/S	5.29	5.64	5.58	5.20	5.38	5.93	5.48	5.44	5.50	5.49
FULFB	G/S	2.57	2.56	2.57	2.57	2.55	2.56	2.57	2.58	2.58	2.58
OBSFC	G/KWH	229.4	249.2	251.1	222.5	223.4	247.4	236.4	240.9	251.1	249.3
EXHTL	DEG-C	363.2	363.2	363.2	363.2	363.2	363.2	363.2	363.2	327.3	327.3
EXCTL	DEG-C	1376.1	1376.1	1376.1	1376.1	1376.1	1376.1	1376.1	1376.1	1376.1	1376.1
EXHTR	DEG-C	330.1	330.1	330.1	330.1	330.1	330.1	330.1	330.1	354.9	354.9
EXCTR	DEG-C	463.7	463.7	463.7	463.7	463.7	463.7	463.7	463.7	465.5	465.5
TIARA	DEG-C	31.1	31.1	31.1	31.1	31.1	31.1	31.1	31.1	29.8	29.8
TIARB	DEG-C	30.8	30.8	30.8	30.8	30.8	30.8	30.8	30.8	30.9	30.9
COLAT	DEG-C	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.3	22.6	22.6
OILTP	DEG-C	96.5	96.5	96.5	96.5	96.5	96.5	96.5	96.5	96.4	96.4
CYLHT	DEG-C	94.0	94.0	94.0	94.0	94.0	94.0	94.0	94.0	89.6	89.6
H2O-O	DEG-C	-658.3	-658.3	-658.3	-658.3	-658.3	-658.3	-658.3	-658.3	-658.3	-658.3
FULTI	DEG-C	29.7	29.7	29.7	29.7	29.7	29.7	29.7	29.7	30.4	30.4
FULTO	DEG-C	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.6	33.0	33.0
EXHDP	KPA	-11.373	-11.347	-11.513	-11.543	-11.485	-11.415	-11.371	-11.296	-11.340	-11.522
EOILP	KPA	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
FUELP	KPA	131.7	138.0	140.4	135.4	129.1	133.6	135.5	136.0	132.7	131.6

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                              O R F  -  E N G I N E   T E S T   F A C I L I T Y

                                            S A M P L E   D A T A

ENGINE  TYPE:                                ENGINE MODEL:
OPERATOR NAME:                                   FUEL TYPE  D\M 30%                   ENGINE SERIAL NUMBER: 6283999
                                                                                            CELL NAME: CL-4
-----------------------------------------------------------------------------------------------------------------------
TIME
                  18:19:44  18:19:45  18:19:46  18:19:47  18:19:48  18:19:49  18:19:50  18:19:51  18:19:52  18:19:53
SAMPLE                 111       112       113       114       115       116       117       118       119       120
STEP                   111       112       113       114       115       116       117       118       119       120
ENGSP   RPM         2316.0    2320.0    2339.0    2295.0    2308.0    2343.0    2356.0    2317.0    2301.0    2346.0
ETORQ   N-M          343.9     364.1     358.7     352.0     352.7     341.2     330.4     335.8     332.4     306.8
CTORQ   N-M          339.2     359.2     353.9     347.2     347.9     336.3     325.7     331.0     327.7     302.4
FULFA   G/S           5.15      5.68      5.89      5.41      5.60      5.94      5.69      5.03      5.19      5.85
FULFB   G/S           2.58      2.56      2.56      2.57      2.58      2.59      2.60      2.62      2.60      2.58
OBSFC   G/KWH        222.4     231.0     241.3     230.2     236.7     255.6     251.5     222.1     233.1     279.2

EXHTL   DEG-C        327.3     327.3     327.3     327.3     327.3     363.7     363.7     363.7     363.7     363.7
EXCTL   DEG-C       1376.1    1376.1    1376.1    1376.1    1376.1    1375.0    1375.0    1375.0    1375.0    1375.0
EXHTR   DEG-C        354.9     354.9     354.9     354.9     354.9     357.2     357.2     357.2     357.2     357.2
EXCTR   DEG-C        465.5     465.5     465.5     465.5     465.5     464.6     464.6     464.6     464.6     464.6
TIARA   DEG-C         29.8      29.8      29.8      29.8      29.8      31.1      31.1      31.1      31.1      31.1
TIARB   DEG-C         30.9      30.9      30.9      30.9      30.9      30.6      30.6      30.6      30.6      30.6
COLAT   DEG-C         22.6      22.6      22.6      22.6      22.6      22.6      22.6      22.6      22.6      22.6
OILTP   DEG-C         96.4      96.4      96.4      96.4      96.4      96.7      96.7      96.7      96.7      96.7
CYLHT   DEG-C         89.6      89.6      89.6      89.6      89.6      93.2      93.2      93.2      93.2      93.2
H2O-O   DEG-C       -658.3    -658.3    -658.3    -658.3    -658.3    -658.3    -658.3    -658.3    -658.3    -658.3
FULTI   DEG-C         30.4      30.4      30.4      30.4      30.4      29.4      29.4      29.4      29.4      29.4
FULTO   DEG-C         33.0      33.0      33.0      33.0      33.0      34.1      34.1      34.1      34.1      34.1

EXHDP   KPA        -11.557   -11.466   -11.466   -11.501   -11.441   -11.364   -11.499   -11.513   -11.256   -11.203
EOILP   KPA             .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
FUELP   KPA          143.2     131.9     128.3     153.1     123.4     124.9     136.3     149.8     137.0     144.3
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ORF - ENGINE TEST FACILITY

SAMPLE DATA

ENGINE TYPE:
ENGINE MODEL:
ENGINE SERIAL NUMBER: 6283999
OPERATOR NAME:
FUEL TYPE: DVM 30%
CELL NAME: CL-4

TIME		18:19:54	18:19:55	18:19:56	18:19:57	18:19:58	18:19:59	18:20:00	18:20:01	18:20:02	18:20:03
SAMPLE		121	122	123	124	125	126	127	128	129	130
STEP		121	122	123	124	125	126	127	128	129	130
ENGSP	RPM	2367.0	2366.0	2357.0	2352.0	2337.0	2360.0	2393.0	2346.0	2357.0	2331.0
ETORQ	N-M	271.7	246.1	235.3	236.0	231.3	221.2	183.4	171.9	186.1	198.9
CTORQ	N-M	267.8	242.6	230.4	231.1	226.5	216.6	179.6	168.4	182.2	194.8
FULFA	G/S	5.28	4.69	4.47	4.38	4.40	4.72	4.41	3.59	3.91	3.96
FULFB	G/S	2.57	2.57	2.54	2.49	2.44	2.38	2.33	2.29	2.23	2.17
OBSFC	G/KWH	282.2	276.9	277.3	271.4	279.6	310.8	345.3	306.3	306.7	293.6
EXHTL	DEG-C	363.7	363.7	359.5	359.5	359.5	359.5	359.5	359.5	359.5	359.5
EXCTL	DEG-C	1375.0	1375.0	1364.7	1364.7	1364.7	1364.7	1364.7	1364.7	1364.7	1364.7
EXHTR	DEG-C	357.2	357.2	355.9	355.9	355.9	355.9	355.9	355.9	355.9	355.9
EXCTR	DEG-C	464.6	464.6	465.5	465.5	465.5	465.5	465.5	465.5	465.5	465.5
TIARA	DEG-C	31.1	31.1	31.4	31.4	31.4	31.4	31.4	31.4	31.4	31.4
TIARB	DEG-C	30.6	30.6	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8
COLAT	DEG-C	22.6	22.6	22.2	22.2	22.2	22.2	22.2	22.2	22.2	22.2
OILTP	DEG-C	96.7	96.7	96.3	96.3	96.3	96.3	96.3	96.3	96.3	96.3
CYLHT	DEG-C	93.2	93.2	93.5	93.5	93.5	93.5	93.5	93.5	93.5	93.5
H2O-O	DEG-C	-658.3	-658.3	-658.3	-658.3	-658.3	-658.3	-658.3	-658.3	-658.3	-658.3
FULTI	DEG-C	29.4	29.4	30.5	30.5	30.5	30.5	30.5	30.5	30.5	30.5
FULTO	DEG-C	34.1	34.1	29.1	29.1	29.1	29.1	29.1	29.1	29.1	29.1
EXHDP	KPA	-11.156	-11.168	-11.238	-11.210	-11.142	-11.070	-11.119	-11.221	-11.331	-11.219
EOILP	KPA	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
FUELP	KPA	156.6	155.1	146.1	151.3	154.9	152.9	158.8	161.1	156.5	156.2

ORF - ENGINE TEST FACILITY

SAMPLE DATA

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ENGINE  TYPE:                 ENGINE MODEL:                 ENGINE SERIAL NUMBER  6283999
OPERATOR NAME:                  FUEL TYPE: DVM 30%                      CELL NAME  CL-4
------------------------------------------------------------------------------------------------------------
TIME                18:20:04  18:20:05  18:20:06  18:20:07  18:20:08  18:20:09  18:20:10  18:20:11  18:20:12  18:20:13
SAMPLE                   131       132       133       134       135       136       137       138       139       140
STEP                     131       132       133       134       135       136       137       138       139       140
ENGSP   RPM           2357.0    2393.0    2368.0    2313.0    2343.0    2369.0    2367.0    2355.0    2341.0    2319.0
ETORQ   N-M            196.2     190.8     200.3     221.2     223.9     211.1     194.2     189.5     195.5     207.7
CTORQ   N-M            193.4     188.1     197.4     218.0     220.7     208.0     191.4     186.7     192.7     204.6
FULFA   G/S             4.39      4.58      3.98      3.65      4.53      4.77      4.24      3.94      3.84      3.94
FULFB   G/S             2.12      2.09      2.08      2.07      2.03      2.02      2.05      2.05      2.05      2.02
OBSFC   G/KWH          326.0     344.7     288.3     245.1     297.1     328.0     317.0     303.8     288.7     281.3

EXHTL   DEG-C          340.7     340.7     340.7     340.7     340.7     340.7     340.7     330.1     330.1     330.1
EXCTL   DEG-C         1375.0    1375.0    1375.0    1375.0    1375.0    1375.0    1375.0    1376.1    1376.1    1376.1
EXHTR   DEG-C          332.4     332.4     332.4     332.4     332.4     332.4     332.4     323.1     323.1     323.1
EXCTR   DEG-C          456.3     456.3     456.3     456.3     456.3     456.3     456.3     465.5     465.5     465.5
TIARA   DEG-C           31.2      31.2      31.2      31.2      31.2      31.2      31.2      31.1      31.1      31.1
TIARB   DEG-C           30.6      30.6      30.6      30.6      30.6      30.6      30.6      30.5      30.5      30.5
COLAT   DEG-C           22.0      22.0      22.0      22.0      22.0      22.0      22.0      21.7      21.7      21.7
OILTP   DEG-C           92.7      92.7      92.7      92.7      92.7      92.7      92.7      96.7      96.7      96.7
CYLHT   DEG-C           93.1      93.1      93.1      93.1      93.1      93.1      93.1      93.8      93.8      93.8
H2O-O   DEG-C         -658.3    -658.3    -658.3    -658.3    -658.3    -658.3    -658.3    -658.3    -658.3    -658.3
FULTI   DEG-C           29.1      29.1      29.1      29.1      29.1      29.1      29.1      27.2      27.2      27.2
FULTO   DEG-C           33.7      33.7      33.7      33.7      33.7      33.7      33.7      33.5      33.5      33.5

EXHDP   KPA          -11.198   -11.282   -11.487   -11.357   -11.228   -11.217   -11.186   -11.242   -11.312   -11.457
EOILP   KPA               .0        .0        .0        .0        .0        .0        .0        .0        .0        .0
FUELP   KPA            150.7     156.3     161.2     153.1     141.8     159.3     150.5     157.9     169.2     146.0
```

```
                          ORF - ENGINE TEST FACILITY

                                 SAMPLE DATA

ENGINE TYPE:                    ENGINE MODEL:                     ENGINE SERIAL NUMBER: 6283999
OPERATOR NAME:                     FUEL TYPE: DVM 30%                        CELL NAME: CL-4
--------------------------------------------------------------------------------------------------------------
TIME                18:20:14 18:20:15 18:20:16 18:20:17 18:20:18 18:20:19 18:20:20 18:20:21 18:20:22 18:20:23
SAMPLE                   141      142      143      144      145      146      147      148      149      150
STEP                     141      142      143      144      145      146      147      148      149      150
ENGSP   RPM           2363.0   2363.0   2349.0   2340.0   2362.0   2385.0   2351.0   2341.0   2324.0   2346.0
ETORQ   N-M            232.6    252.9    254.9    244.1    217.8    190.8    183.4    196.9    232.0    250.8
CTORQ   N-M            229.2    249.2    251.2    240.5    214.6    186.4    179.1    192.3    226.6    245.0
FULFA   G/S             4.72     4.90     4.81     4.51     4.59     4.41     3.87     3.87     4.18     4.97
FULFB   G/S             2.00     2.01     2.05     2.08     2.09     2.10     2.10     2.07     2.04     2.02
OBSFC   G/KWH          295.4    282.2    276.2    271.6    306.9    333.3    308.5    288.4    266.8    290.3

EXHTL   DEG-C          330.1    330.1    330.1    330.1    330.1    322.6    322.6    322.6    322.6    322.6
EXCTL   DEG-C         1376.1   1376.1   1376.1   1376.1   1376.1   1362.9   1362.9   1362.9   1362.9   1362.9
EXHTR   DEG-C          323.1    323.1    323.1    323.1    323.1    317.6    317.6    317.6    317.6    317.6
EXCTR   DEG-C          465.5    465.5    465.5    465.5    465.5    463.6    463.6    463.6    463.6    463.6
TIARA   DEG-C           31.1     31.1     31.1     31.1     31.1     31.1     31.1     31.1     31.1     31.1
TIARB   DEG-C           30.5     30.5     30.5     30.5     30.5     26.7     26.7     26.7     26.7     26.7
COLAT   DEG-C           21.7     21.7     21.7     21.7     21.7     22.0     22.0     22.0     22.0     22.0
OILTP   DEG-C           96.7     96.7     96.7     96.7     96.7     96.8     96.8     96.8     96.8     96.8
CYLHT   DEG-C           93.8     93.8     93.8     93.8     93.8     93.7     93.7     93.7     93.7     93.7
H2O-O   DEG-C         -658.3   -658.3   -658.3   -658.3   -658.3   -658.3   -658.3   -658.3   -658.3   -658.3
FULTI   DEG-C           27.2     27.2     27.2     27.2     27.2     30.1     30.1     30.1     30.1     30.1
FULTO   DEG-C           33.5     33.5     33.5     33.5     33.5     28.3     28.3     28.3     28.3     28.3

EXHDP   KPA          -11.564  -11.408  -11.317  -11.177  -11.109  -11.165  -11.289  -11.555  -11.553  -11.249
EOILP   KPA               .0       .0       .0       .0       .0       .0       .0       .0       .0       .0
FUELP   KPA            143.2    145.6    154.3    155.7    156.6    164.4    161.0    156.0    145.5    144.7
```

APPENDIX E

Analytical Data for the Analysis of Carbonyl Compounds in the Exhaust of a Deutz F8L 413 F/W Engine Fuelled with Diesel Fuel and Methanol/Diesel Emulsion

TABLE 1

Carbonyl DNPH Concentrations (mg) in Diesel and Diesel-Methanol Exhaust Samples

Carbonyl DNPH	Test 1	Test 2	Test 3	Test 4
Formaldehyde	2.568	2.594	0.753	1.388
Acetaldehyde	0.650	0.746	0.325	0.464
Acetone	0.236	0.807	0.382	0.571
Crotonaldehyde	ND*	ND	ND	ND
MEK & Iso-butryaldehyde	0.038	0.023	0.085	0.100
Benzaldehyde	ND	ND	ND	ND
Hexanaldehyde	ND	ND	ND	ND

* ND = none detected.

TABLE 2

HPLC Conditions for Carbonyl Analysis

Injection Volume	50 µL
Column	C_{18} RP Ultrasphere ODS (4.6 mm x 25 cm)
Flow Rate	1.00 mL/min.
Gradient Program	60% CH_3CN - 90% CH_3CN in 45 mins.
Detector	UV λ 365 nm @ 1.0 AuFs
Data System	SP-4100 Att. X1
Chart Speed	0.5 cm/min.
Pressure	1660-1520 psi

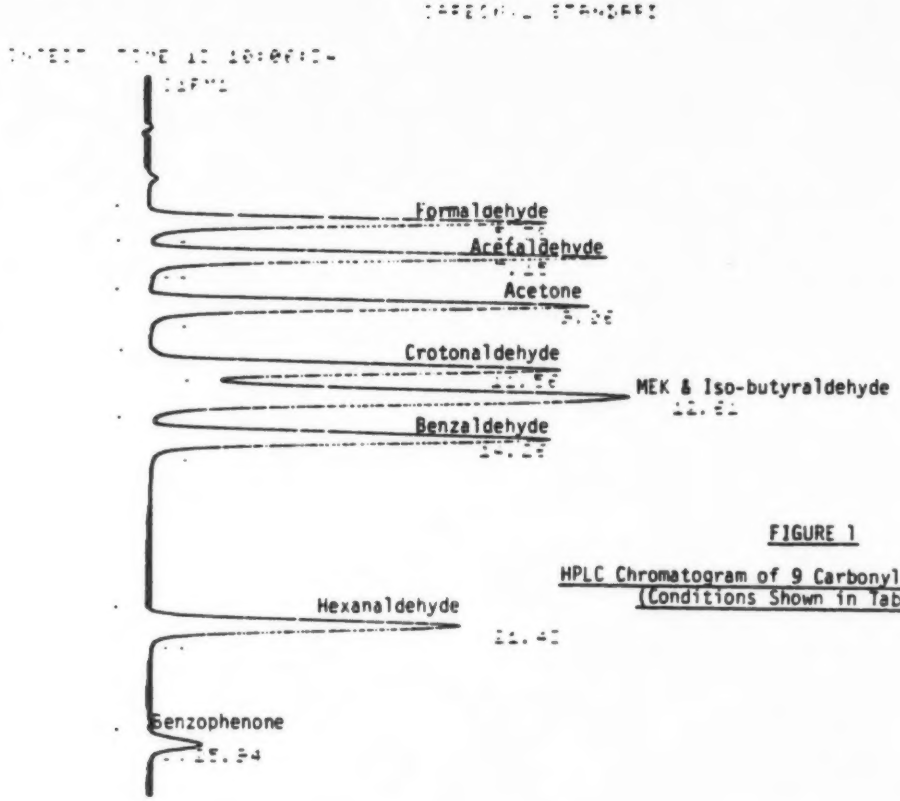

FIGURE 1

HPLC Chromatogram of 9 Carbonyl DNPH Standard (Conditions Shown in Table 2)

```
CANMET FUEL ADDITIVES          10 10:06:14

FILE 1      METHOD  0.      RUN  20       INDEX  20

PEAK#      AREA%         RT       AREA BC

   1       10.533      5.78      17690 01
   2       12.966      7.15      21778 01
   3       13.251      9.06      22305 01
   4       13.916     11.56      23203 02
   5       11.166     12.61      18905 02
   6       13.795     14.29      23167 02
   7       10.807     21.43      18149 01
   8        1.636     25.94       2747 01

TOTAL     100.                   167941
```

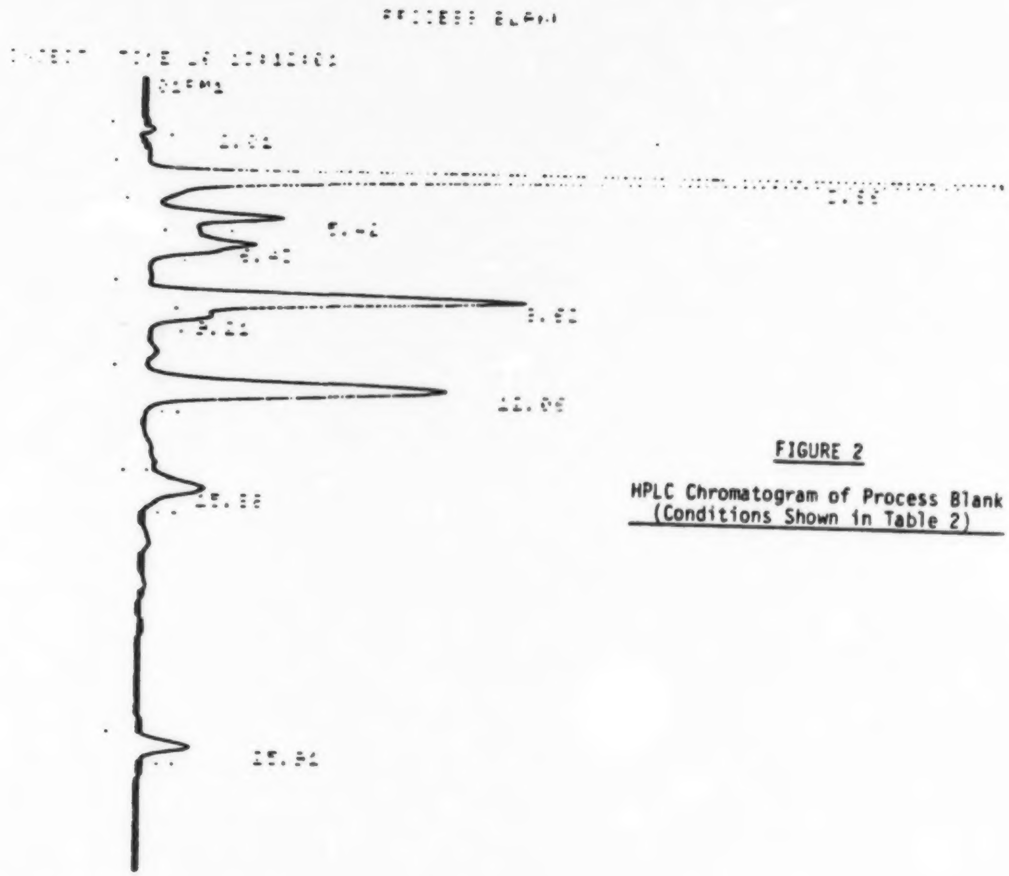

FIGURE 2

HPLC Chromatogram of Process Blank (Conditions Shown in Table 2)

```
JANKET FUEL ADDITIVES              18 10:12:01

FILE 1      METHOD  0.      RUN  18       INDEX  18

PEAK#       AREA%        RT      AREA BC

  1          0.22       2.01      229 01
  2         39.847      3.66    40902 05
  3          4.221      5.42     4333 05
  4          4.211      6.42     4323 01
  5         21.003      8.62    21560 02
  6          2.39       9.21     2453 01
  7         21.443     12.06    22011 01
  8          3.907     15.58     4011 01
  9          2.637     25.91     2707 01

TOTAL       100.                102650
```

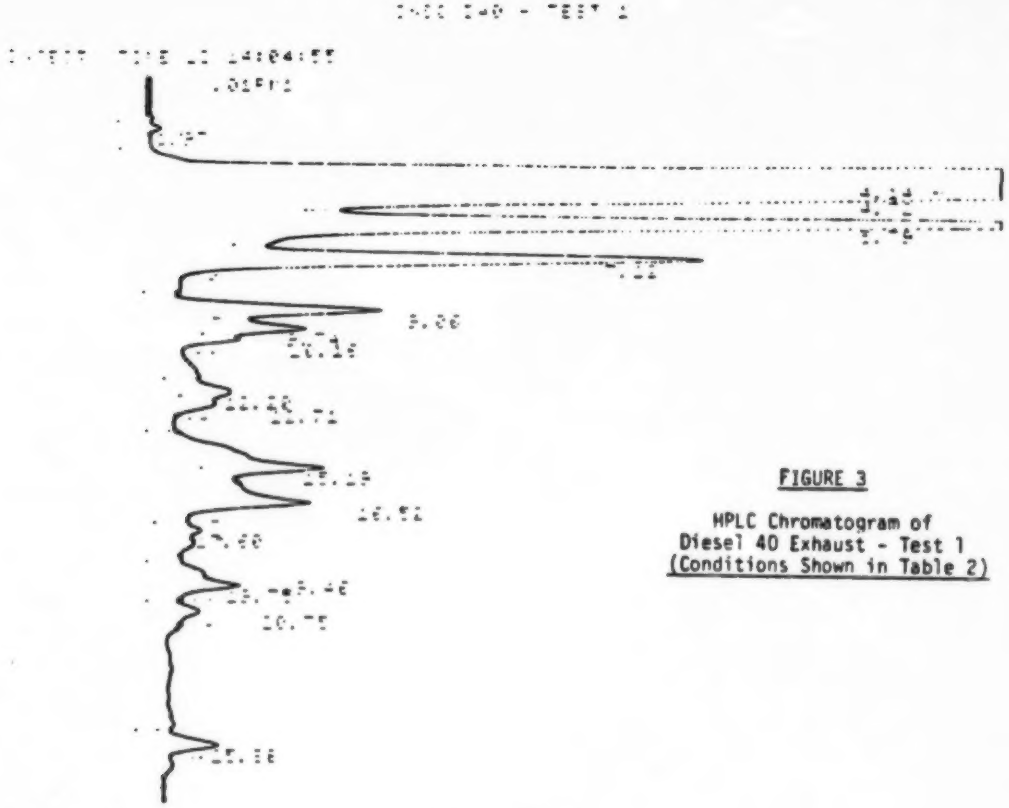

FIGURE 3

HPLC Chromatogram of
Diesel 40 Exhaust - Test 1
(Conditions Shown in Table 2)

```
INJD METHANOL                        12 14:04:55

FILE 1      METHOD  0.      RUN  26      INDEX  26

PEAK#       AREA%         RT       AREA BC

   1         0.067       1.97        278 01
   2        50.059       4.14     207350 02
   3         9.902       4.72      41015 02
   4        20.256       5.79      83904 06
   5         5.894       7.12      24412 05
   6         2.716       9.06      11252 02
   7         1.845       9.74       7642 02
   8         0.423      10.16       1753 03
   9         0.629      11.2        2607 02
  10         0.348      12.71       1442 03
  11         3.183      15.19      13183 02
  12         2.752      16.52      11399 03
  13         0.079      17.6         325 01
  14         0.286      19.46       1186 02
  15         0.693      19.75       2872 03
  16         0.216      20.75        896 01
  17         0.625      25.38       2590 01

TOTAL      100.                   414269
```

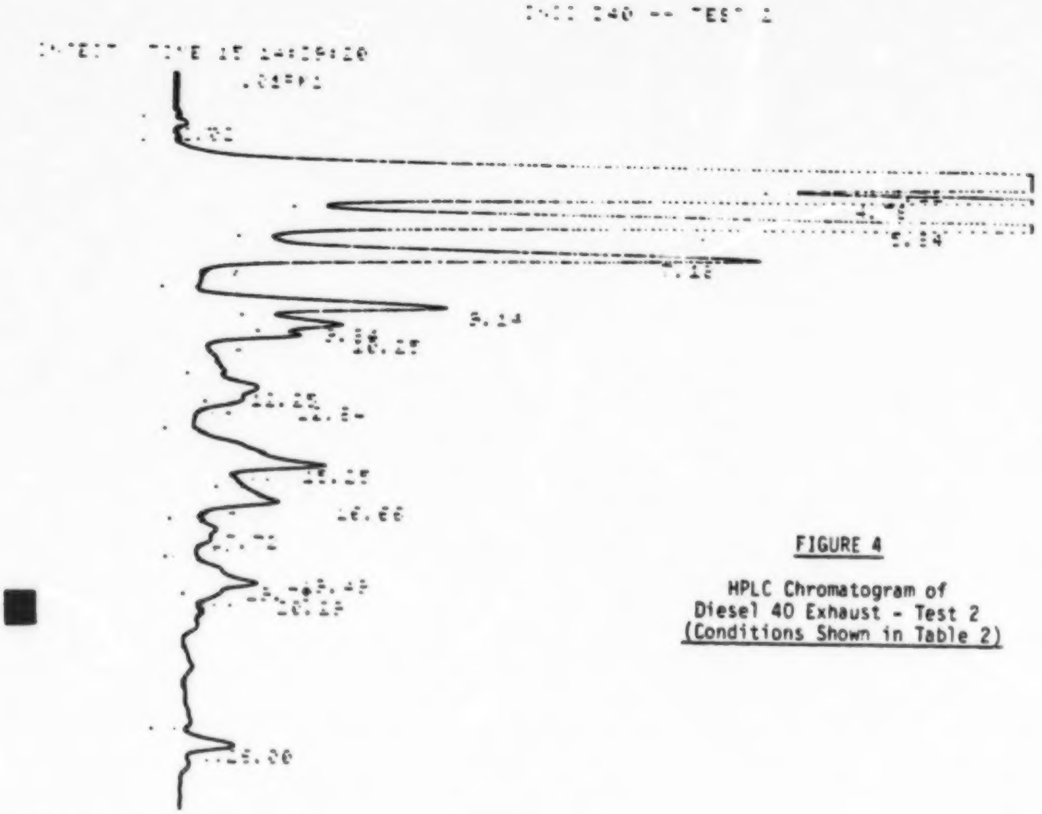

FIGURE 4

HPLC Chromatogram of
Diesel 40 Exhaust - Test 2
(Conditions Shown in Table 2)

```
INJ METHANOL                          15 14:29:20

FILE 1        METHOD  0.       RUN  28       INDEX  28

PEAK#         AREA%            RT        AREA BC

    1          0.065          2.02        262 01
    2         44.381          4.11     168416 02
    3         13.892          4.78      52719 02
    4         21.562          5.94      81824 06
    5          7.128          7.18      27049 05
    6          3.575          9.14      13567 02
    7          2.267          9.54       8602 02
    8          0.892         10.25       3389 02
    9          0.967         12.25       3670 02
   10          0.217         12.84        824 02
   11          1.115         15.25       4227 02
   12          0.697         16.66       2645 01
   13          0.299         17.72       1135 01
   14          0.282         19.45       1069 02
   15          0.918         19.78       3482 02
   16          0.076         20.29        289 02
   17          0.659         26.         2501 02

TOTAL        100.                    379471
```

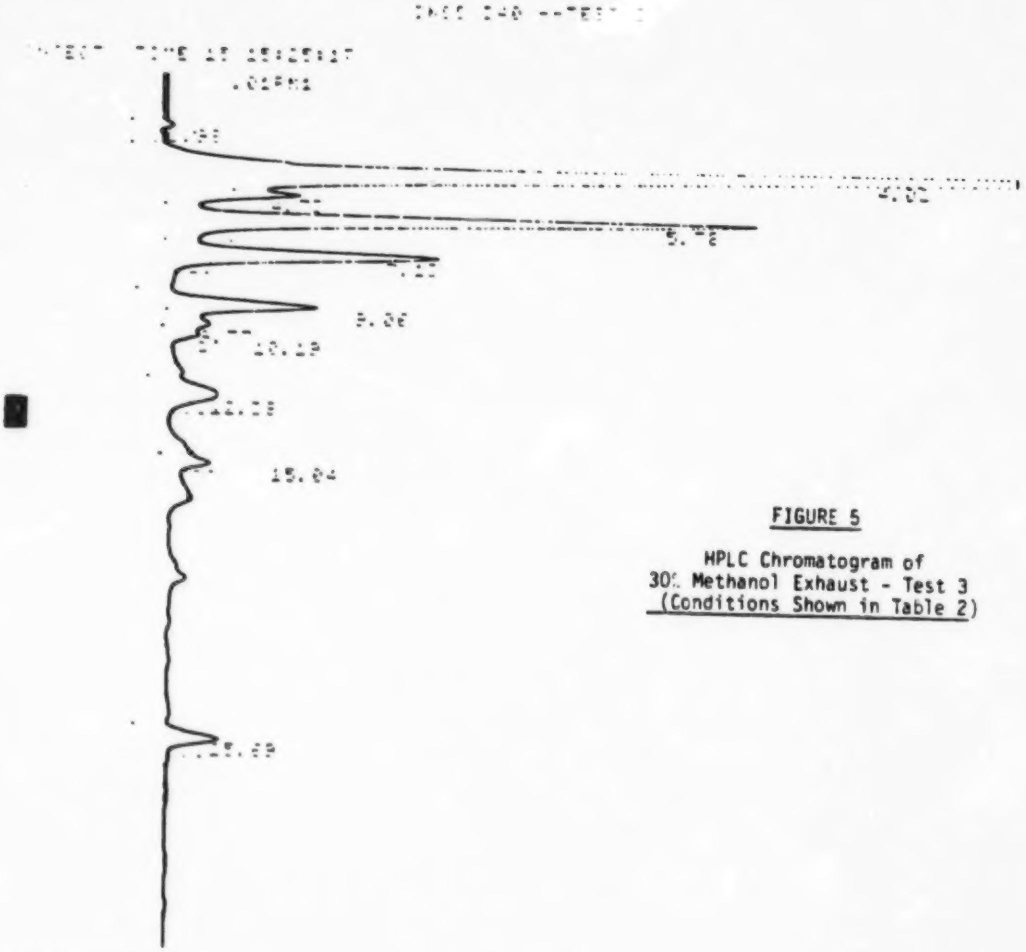

FIGURE 5

HPLC Chromatogram of
30% Methanol Exhaust - Test 3
(Conditions Shown in Table 2)

```
INCO METHANOL                        15 15:25:17

FILE 1      METHOD  0.      RUN  29      INDEX  29

PEAK#       AREA%     .    RT        AREA BC

    1          0.15        1.96        201 01
    2         53.985       4.02      72421 02
    3          3.703       4.73       4967 01
    4         19.234       5.76      25802 03
    5          9.53        7.13      12764 01
    6          6.05        9.06       8170 02
    7          1.559       9.77       2091 02
    8          0.683      10.19        917 03
    9          1.468      12.18    [illegible] 01
   10          0.539      15.24        723 01
   11          2.025      25.29       2716 01

TOTAL       100.                    134150
```

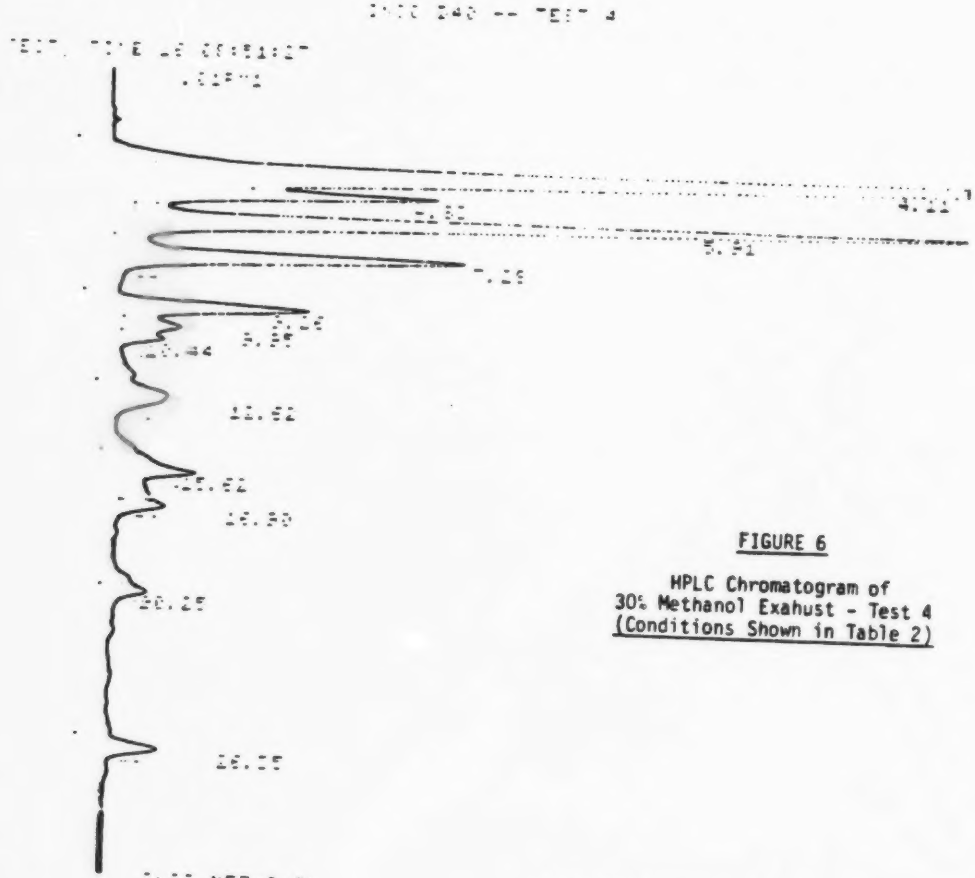

FIGURE 6

HPLC Chromatogram of
30% Methanol Exahust - Test 4
(Conditions Shown in Table 2)

```
DATA METHANOL                              16 08:51:27

FILE 1      METHOD  0.      RUN  30      INDEX  30

PEAK#       AREA%         RT        AREA BC

   1        46.374        4.41      89285 02
   2         8.027        4.82      15455 02
   3        23.105        5.91      44485 06



   4         8.878        7.28      17092 05
   5         5.422        9.26      10441 02
   6    [illegible]       9.95   [illegible] 02
   7         0.837       10.44       1612 02
   8         1.386       12.82       2670 01
   9         1.548       15.62       2980 01
  10         0.4         16.9         771 02
  11         0.351       20.25        675 01
  12         1.32        26.35       2541 01

TOTAL      100.                    192521
```

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